Republic of Iraq
Ministry of Higher Education and Scientific Research
University of Kerbala
College of Engineering / Civil Department

Behavior of Reinforced Concrete Columns Buried into Different Types of Aggressive Soils

A Thesis

Submitted to the College of Engineering of

The University of Kerbala

In Partial Fulfillment of the Requirements for the Degree of

Master of Science in Civil Engineering / Infrastructure

By

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November 2017 A.D. *Safer 1439 A.H.*

بسم الله الرحمن الرحيم

﴿وَمَا تَوْفِيقِي إِلَّا بِاللَّهِ عَلَيْهِ

تَوَكَّلْتُ وَإِلَيْهِ أُنِيبُ﴾

[سورة هود الآية:88]

صدق الله العظيم

Certification

I certify that this thesis titled **Behavior of Reinforced Concrete Columns Buried into Different Types of Aggressive Soils**, was prepared by '*Zahraa Fadhil Hanash,* under my supervision at the University of Kerbala in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

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Acknowledgements

In the name of Allah, the most gracious, the most merciful First, great thanks are to ***ALLAH, HIS MAJESTY***, for enabling me to complete this work.

My sincere appreciation and deepest gratitude are to my supervisors ***Asst. Prof. Dr. Laith Sh. Rasheed & Prof. Dr. Shakir A. Salih***. I had the honor of being under their guidance, and supervision. Their constructive suggestion, patience and continuous encouragement was highly acknowledged throughout this research.

My special thanks go to (***My Father & My Mother***) who have much of the credit for being always helpful, care, support and love: throughout the research period.

I do not know how I can express my profound respect and thanks to my family (***My brothers, My sisters & My brothers' sons***) for their encouragement, help, support and love.

I must also thank all (***My friends and Colleagues***) who have given me support, advice and assistance.

Finally, wish to express my deepest thanks to the head and staff of Civil Engineering Department College of Engineering University of Karbala for their facilities and assistance throughout this study.

Zahraa F. Hanash

2017

Dedication

To savior of humanity, my sir & mola

Imam al-hujjah Muhammad ibn Hasan

al-Mahdi **“**God hurry his appear”

Zahraa F. Hanash
2017

Abstract

Concrete resistance to sulfate attack is one of the most important properties for maintaining durability of concrete. The main objective of this research is to evaluate the performance of several types of reinforced concrete columns buried in two pits at a 3-meter depth in one of the agricultural areas in the holy city of Kerbala, one contains a sandy soil with sulfur salts (SO_3 = 10.609%) and the other contains a clayey soil with salinity ratio of (SO_3 = 2.61%). In this research, three types of concrete mixes have been produced and utilized: normal strength concrete, polymeric concrete, and high strength concrete. A total of 21 reinforced concrete columns, 126 concrete cubes, and 63 concrete cylinders were prepared. The columns and reference concrete specimens were cured for 28 days with tap water and then buried in soils for (60, 150, 240) days. A number of laboratory testing methods have been carried out on the specimens: (axial compression strength of concrete columns, compressive strength test for concrete cubes, splitting tensile strength of concrete cylinders, absorption test, voids ratio and density of concrete cubes). These tests have been conducted at different ages of exposure.

Test results showed that the aggressive soils (containing sulfates and chlorides) affect the performance of all types of concrete mixes negatively with age of exposure. The deterioration was more for specimen buried in sandy soils. It is found that the resistance of high-strength concrete to aggressive soils was better than other types of concrete.

The percentage of decrease in compressive strength of concrete columns exposed to aggressive solutions in the clayey soil for normal, polymer, and high-strength concretes ranged from (0.95-12.51) %, (20.28-24.96) %, and (1.5-15.62) % respectively. The percentage of decrease in compressive strength capacity of polymer, and high-strength concrete columns exposed to aggressive solutions in

the sandy soils ranged between (20.03-37.52) %, and (0-18.74) % respectively, compared to the reference concrete columns not buried in soils.

In contrast a development in strength was observed for normal concrete columns exposed to aggressive sandy soils, it reads up to (11.7 %) after (240 days) of exposure. The durability test results (absorption and voids ratio) showed a deterioration (increases) for polymer and high strength concrete mixes, while it was not observed in normal concrete mix.

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List of Abbreviations

Abbreviations	Description
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British Standards
R.C.	Reinforced concrete
$Cl^- + SO_4^=$	Chloride and Sulfate Ions
C-S-H	Calcium Silicate Hydrate
PC	Polymer Concrete
NC	Normal Concrete
SBR	Styrene Butadiene Rubber
LMC	Latex-Modified Concrete
PIC	Polymer Impregnated Concrete
PPCC	Polymer Portland Cement Concrete
HSC	High Strength Concrete
NSC	Normal Strength Concrete
PSC	Polymer Strength Concrete
SP	Superplasticizer
W/C	Water to Cement Ratio

List of Notation

Notation	***Description***
E_s	Static Modulus of Elasticity of Steel (GPa)
f_{SP}	Splitting Tensile Strength of Concrete (MPa)
A_S	Area of Steel, mm^2
A_g	Gross Area of Concrete, mm^2
Gs	Specific gravity
Pcr	Cracking Load, kN
Pu	Ultimate Load, kN
PL	Plastic limit
LL	Liquid limit
PI	Plasticity index

Chapter One

Introduction

CHAPTER ONE

Introduction

1.1 General:

Concrete is a composite complicated matrix with properties that change with time. Concrete strength provided by water treatment in-service life for concrete can be improved by constant hydration, as in foundations and water retention structures. However, concrete strength can decrease over time due to internal or external sulfate attack. In the past 30 to 40 years, lake durability has become a major concern in construction. In some developing countries such as Iraq 30% to 50% of the infrastructure budget goes to the repair and maintenance of facilities already in place, so the government and developers are looking for ways to reduce the cost of maintenance rather than looking for ways to reduce the initial cost of construction ***(Ho, 2003)***.

1.2 Effect of Aggressive Solutions on Infrastructure R.C. Members:

The underground R.C. structures especially footings, piers, piles and column necks are always subjected to aggressive environmental conditions during their exploitation. These conditions are represented by the aggressive sulfate and chloride attack from surrounded soil or underground water. Which implies to deterioration of concrete cover and penetration of sulfate and chloride ions to the interior of concrete elements, according to that, the actual strength of RC elements decreases and corrosion damage of embedded steel bars attended with large deformations of concrete and steel increases ***(Rashwan et al., 2006)***.

Deterioration of concrete caused by aggressive environments can be the result of contact with gases or solution of many chemicals, but in the ground, it is generally due to sulfate salts. Sulfate attack causes concrete deterioration by chemical and/ or physical reactions. In this phenomenon, sulfate ions penetrating from groundwater and soils in concrete mainly react with aluminate phase of cement. As a result, gypsum and an "ettringite" type salt are produced that cause concrete deterioration due to expansion and disruption ***(Ho, 2003).***

The amount of damage on concrete as a result of the external sulfates attacks depends on the concentration and type of these sulfates and on the quality of the concrete. In permeable concrete, dissolved sulfate ions from external sources penetrate into the concrete and react with cement hydration processes. Therefore, the use of low permeability concrete will be the first step in preventing the penetration of sulfate ions into the concrete.

Underground structures or fundamentals such as foundations, pipes, tunnels, columns and piles are exposed to sulfate attack. White color appears on the surface of the damaged concrete. Damage appears at edges and corners, finally reducing to cracking or even failure crashing.

1.3 Research Significance:

Sulfate ions are found in groundwater and soil especially in southern areas of Iraq. Concrete structures at the regions of these areas that subjected to attack from sulfates may be suffered from two types of damage; loss of strength of the matrix due to degradation of calcium-silicate-hydrate (C-S-H), and volumetric extension due to the formation of gypsum or ettringite that leads to cracking. Protective against sulfate attack needs reducing the porousness of concrete, whereby low porousness characteristics of concrete can delay the service live of a structure that is subjected to severe exposure conditions ***(Obla et al., 2006).***

The present study represents an attempt to produce reinforced concrete that can stand up against sulfate attack investigating different types such as normal concrete, polymer concrete, and high strength reinforced concrete included many admixtures and then studying the strength and durability of these types of concrete.

According to the available literature review there is very limited work that has been published concerning the effect of sulfates in groundwater and soil on some mechanical properties of these types of concrete that buried in different soils.

1.4 Objective and Scope:

The main aim of the present work is to evaluate the effect of sulfate salts in groundwater and soil on strength and durability characteristics of normal, polymer and high strength reinforced concrete columns under pure axial compression force. Through this investigation, 21 reinforced concrete columns are tested, as well as 126 cubes are performed to cover a compressive strength, absorption, density, and voids tests. Splitting tensile strength are undertaken on (63) cylinders. The specimens are buried in sandy and clayey soils, for up to (240) days, in an aggressive solution containing ($Cl^- + SO_3^=$) at a concentration equal to those present in soil and groundwater of the southern parts of Iraq.

1.5 Research Layout:

The research work in the present thesis is covered in five chapters:

Chapter one: presents an introduction to the subject and the objectives of this work. Chapter two: includes a review of relevant literature regarding the normal, polymer, and high strength reinforced concrete and about external sulfate attack. Chapter three: deals with the materials, mix proportions, methods of testing and experimental program details. Chapter four: demonstrates the results of the experimental work, graphical representation of the results and their discussion. Chapter five: introduces the conclusions derived from this study and recommendations for future research works.

Chapter Two

Literature Review

CHAPTER TWO

Literature Review

2.1 General:

This Chapter discusses the structural behavior of compression members made from different types of concrete exposed to aggressive soils, and illustrates the nature of soils and groundwater in Kerbala city.

It is important to review the infrastructure reinforced concrete members, which exposed to the aggressive environment, and the types of concrete which suitable to be used in such projects.

2.2 Infrastructure Reinforced Concrete Members:

At present, buried underground members are typically considered as a part which are not separate from the infrastructure and are used in many fields, such as sewage water, railroad, highway and water transport networks ***(Hashash et al., 2001).***

Footings, piers, piles and column necks are an example of underground infrastructure reinforced concrete structures. They are usually exposed to aggression conservation surroundings through the period of their operation ***(Rashwan et al., 2006).***

The piles are deep foundations which are used to transmit service loads from the structure into the ground. For the foundation of the fine soil, it is readily qualified for hard geological sets and all types of load conditions. Piles have the high bearing capacity, good constancy, and small variance disbursement more than other types of foundation, therefore; it is widely used in infrastructure engineering ***(Wei et al., 2008).***

One of the most important threats on the piles buried underground is the risk of exposure to the sulfate. This is the point that will be covered by the research, which is the impact of sulfates on the compressive strength of concrete.

2.3 Normal Reinforced Concrete:

The Normal reinforced concrete is the most common type of concrete used for structure purposes. Concrete types can be divided into three groups based on their compressive strength characteristics ***(Mehta, 1986)*** - These groups are defined as follows:

- Low strength concrete less than 20 MPa.
- Moderate strength concrete 20 to 40 MPa.
- High strength concrete more than 40 MPa.

The moderate strength concrete represents the ordinary or normal concrete, the typical proportions of materials in its mixture are shown in the *Table (2-1).*

Table (2-1): Typical concrete mixtures for different types of concrete ***(Mehta, 1986).***

Materials	***Low-strength (kg/m^3)***	***Moderate-strength (kg/m^3)***	***High-strength (kg/m^3)***
Water	178	178	178
Cement	255	356	510
Fine aggregate	801	848	890
Coarse aggregate	1169	1032	872
Cement paste proportion			
percent by mass	18	22.1	28.1
percent by volume	26	29.3	34.3
Water/cement by mass	0.7	0.5	0.35
Strength, MPa	18	30	60

Those three types of concrete weight about 2400 kg/m^3, they are called normal weight concrete ***(Mehta, 1986).***

(Lamond and Pielert, 2006) illustrated the stress-strain relationship in the three types of concrete. *Fig. (2-1)* displays that the deflection is increased quickly after peack region in the higher stress levels.

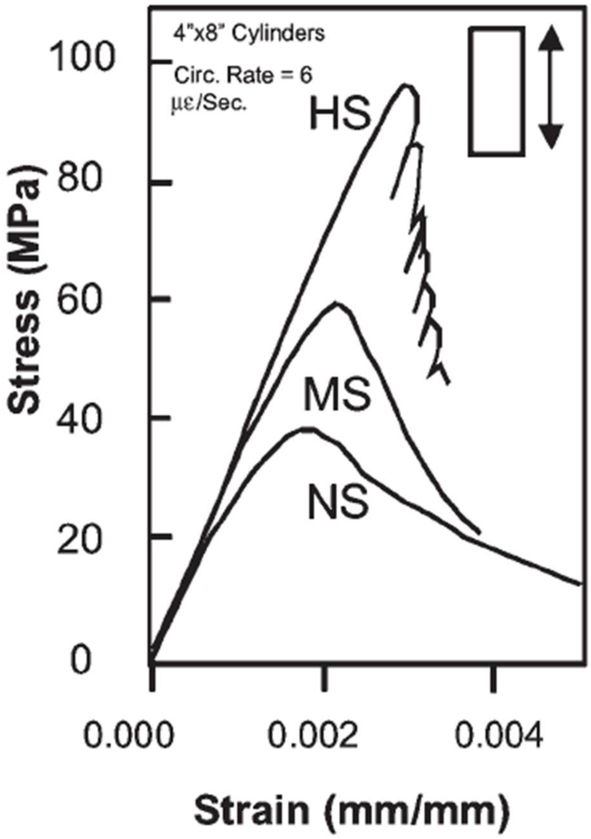

Fig. (2-1): Typical stress-strain plot for normal, medium, and high strength concrete ***(Lamond and Pielert, 2006).***

According to ASTM-C387 the minimum compressive strength for normal concrete in 3, 7, 28 days are listed in the *Table (2-2):*

Table (2-2): Minimum compressive strength concrete for normal concrete ***(ASTM/C387, 2001).***

Concrete Type	***Min. Compressive Strength (MPa)***		
	3 days	***7 days***	***28 days***
Normal weight	…	17	24
Light weight using normal weight sand	…	17	24
Light weight	…	17	24

2.4 Polymer Reinforced Concrete:

The tremendously durable, tough, and strong building material compounds that are inexpensive and sympathetic to the environment can result from the mixture of Portland cement concrete or mortar with polymers. Such materials can reply to the many needs of present and coming construction. Structures in exciting environments, or unreachable for repairs, or subjected to impact, repeated, or dynamic loading may all profit from the use of polymer concrete. The maturing infrastructure can use polymer concrete in repairing ***(Kardon, 1997).***

The polymer in concrete can be divided into three groups: ***(Mehta, 1986)***

Polymer Concrete (PC): is formed from polymerization the aggregate and monomer mixture without bonding material.

Latex-Modified Concrete (LMC): it is also called Polymer Portland Cement Concrete (PPCC). It is polymer used in the concrete mix by a substituting portion of mixing water by polymer latex.

Polymer Impregnated Concrete (PIC): is made from polymer soaking or seeping on the hardened concrete at the site until the polymerization occurs.

The first patent for polymer modification for concrete was in 1923 issued by Cresson, so this concept is not very new ***(Cresson, 1923)***. This patent refers to paving materials with natural rubber latexes, and cement was used as filler. By Lefebure the first patent for the current thought of polymer modification was published by Lefebure ***(Ohama, 1998)*** in 1924. Subsequently, in many countries for 70 years or more, significant research and advance of polymer modification for cement, mortar and concrete have been presented. Thus, many active polymer modification systems for cement and concrete have been advanced, and currently are used in several submissions in the construction industry ***(Al-Nu'man and Al-Hadithi, 2009).***

(LMC) is factory-made in the same way and the same materials of normal concrete but latex complements to it ***(Mehta, 1986)***. Polymer Portland Cement Concrete (PPCC) mixtures were defined by ACI Manual of Concrete Practice Part 5-1990 as normal Portland cement concrete to which a water soluble or blended polymer has been added through the mixing procedure ***(ACI Committee 548 and Fowler, 1992)***. The first latexes like polyvinyl acetate and polyvinylidene chloride are rarely used because it is considered as a threat to the concrete reinforcement, especially in the case where the strength of concrete is weak and moisture present. The most widely polymer used in this time is rubber polymer which is principled on styrene butadiene ***(Mehta, 1986)*** ,

As seen in *Fig. (2-2)*, most commercially available polymer latexes for concrete modifiers are based on elastomeric and thermoplastic polymers which form continuous polymer films when dry. The polymer latexes that are underlined in *Fig. (2-2)* are the foremost ones that are common in the world today ***(Ohama, 1995)***.

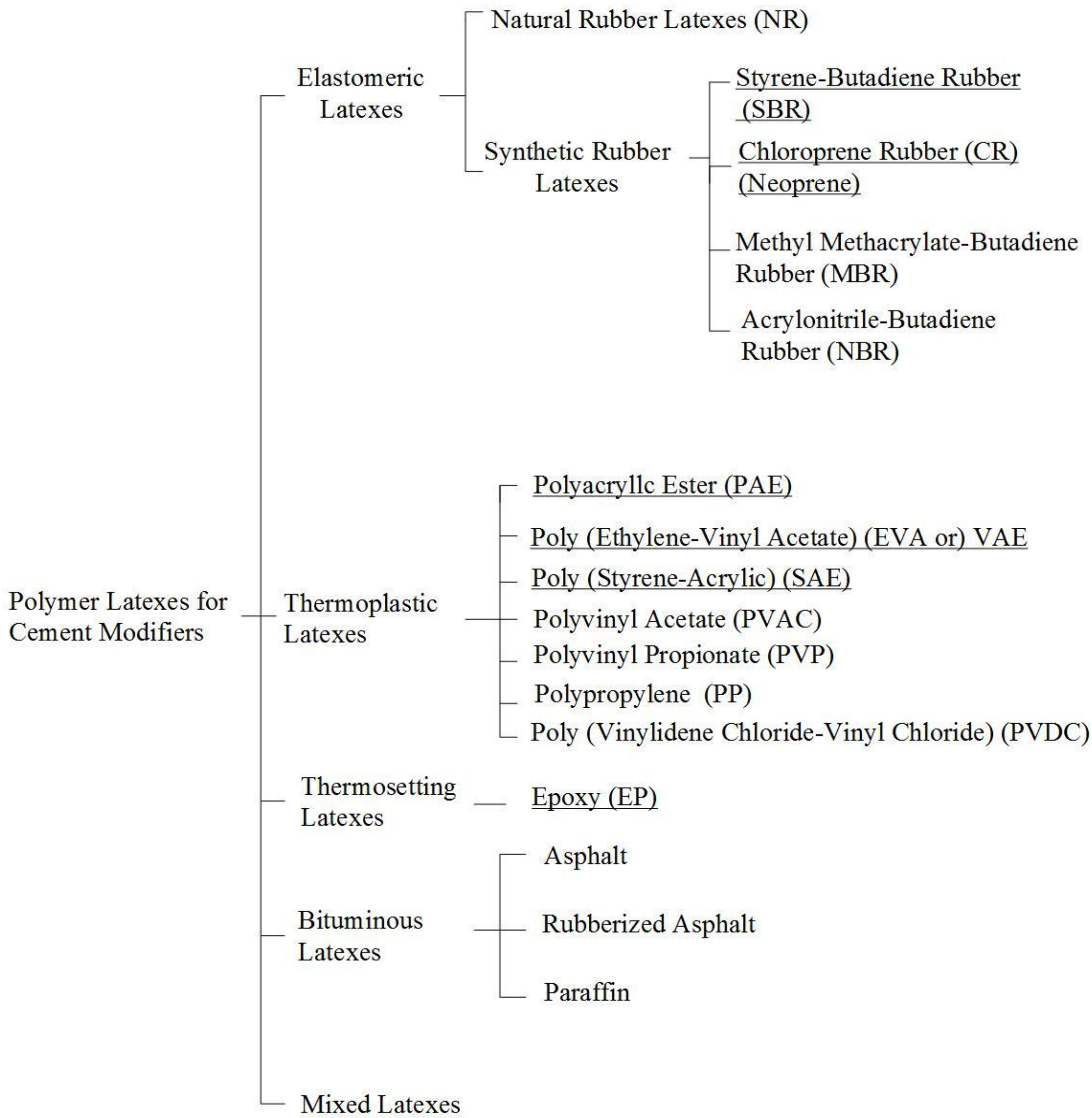

Fig. (2-2): Available polymer latexes for cement modifiers ***(Ohama, 1995)***.

The composition of the latex-modified polymer is subject to cementation and polymer construction. These two processes lead to that composition a co-matrix phase ***(Ohama, 1997)***. Both cement hydration and polymer film formation processes form a co-matrix phase. The co-matrix phase is generally formed according to the simplified model given by ***(Ohama, 1997)***, and integrated model by ***(Ohama, 1995)***, see *Fig. (2-3)*.

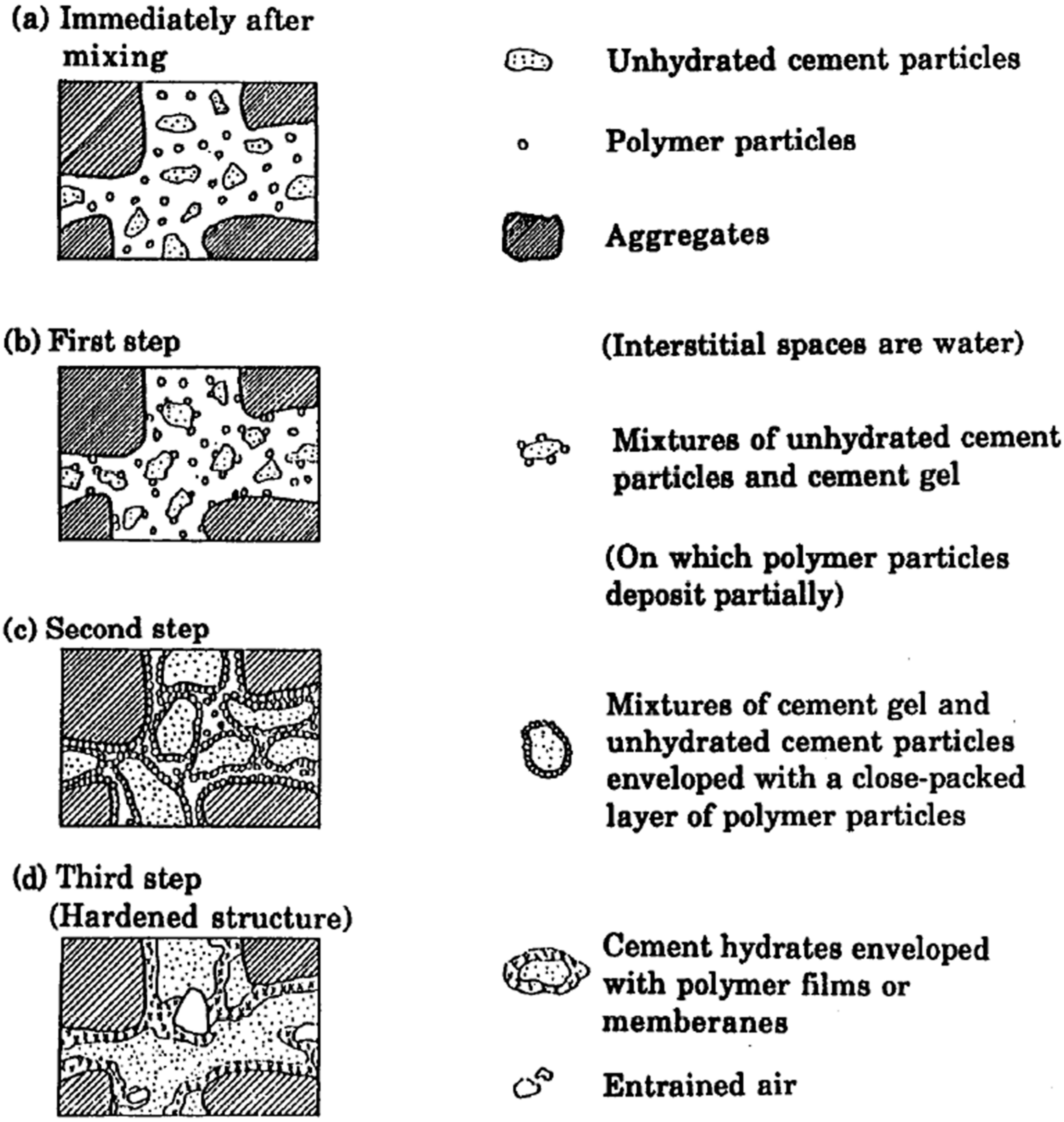

Fig. (2-3): Integrated model of structure formation in polymer concrete
(Ohama, 1995)

The (LMC) is used where the main fear is durability to resist water entry and aggressive solutions. In the concrete mixtures when the polymer (LMC) used the typical W/C ratio varies from 0.4 to 0.45, and the typical cement contents are in the range of 390 to 420 kg/m^3 , *Table (2-3) shows mechanical properties of (LMC) at 28 days (MPa)* ***(Mehta, 1986)***.

Table (2-3): Mechanical properties of (LMC) at 28 days (MPa) ***(Mehta, 1986)***.

Compressive strength (MPa)	40
Tensile strength (MPa)	3.6
Flexural strength (MPa)	7.5
Elastic modulus (MPa)	3800

According to ASTM standard specification for concrete, the minimum compressive strength for (LMC) is 80 percent of reference mixture at each age ***(ASTM/C1438-99, 1999).***

The (LMC) enhances the properties of the concrete mixture. The (LMC) grow great quality, connection, pore structure, impermeability, and durability (solidify defrost resistance, chloride infiltration resistance, carbonation resistance, and weather ability) ***(Islam et al., 2011)***

The polymer reinforced concrete gives good compression, flexural and tensile strength compared to normal reinforced concrete. Some types of a polymer may give a little improvement in compression strength to the structure compared to flexural and tensile strength but, on the other side they give a good bond to other materials and provide high resistance to physical risk and chemical attack. This is explained by the high tensile strength of the polymers themselves and the improved strength of bonding between cement and aggregates. The strength of the (LMC) is inclined by many factors that tend to interrelate with each other. The main factors are the nature of materials used such as cement, aggregates, and polymer latexes; the regulatory factors for mix proportions p/c ratio, w/c ratio, binder-void ratio, air content, etc. curing methods; and testing methods. ***(Islam et al., 2011, Fowler, 1999, Ohama, 1998).***

Styrene Butadiene Rubber (SBR) Polymer is the most widely used material in concrete ***(Ohama, 1995)***. *Fig. (2-4)* shows the chemical structure of (SBR) latexes. Copolymers of butadiene with styrene (SBR), are a group of large-volume synthetic rubbers ***(McCrum et al., 1997)***. High adhesion occurs between the polymer films that form and cement hydrates. This action gives less strain compared to normal concrete and improves the properties of concrete such as flexural and compressive strength and also gives a higher durability ***(Ohama, 1998)***.

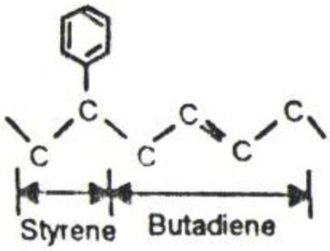

Fig. (2-4): Chemical structures of SBR polymer latexes ***(McCrum et al., 1997)***

Polymer latexes such as (SBR) which consist of very small (0.05-5 mm in diameter) polymer units detached in water as shown in *Fig. (2-5)* are generally formed by mixture polymerization ***(Ohama, 1995)***.

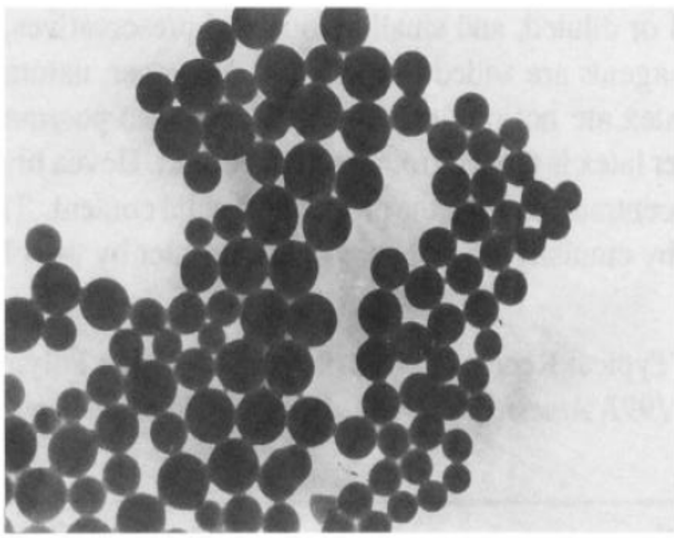

Fig. (2-5): SBR latex particles in water ***(Ohama, 1995)***

(Folic and Radonjanin, 1998) have conducted tests on 180 different sizes and forms of a concrete model. They used (SBR) in their study and they found:

- Compressive strength was slightly increased with the increase of the polymer-cement ratio (1 to 7 percent).
- Tensile strength increased with the increase of polymer cement ratio and the correlation is in the form of a straight line. The increase of flexural strength for concrete modified with 7.5 percent of polymer admixture was 40 percent in relation to the reference concrete.
- The ratio between tensile and compressive strength increased with the polymer admixture increase.
- Water absorption decreased with the increase of polymer cement ratio. Although it was only the case of capillary water absorption, such a positive change is important as it influenced the increase of concrete durability.
- Shrinkage of the modified concrete with 7.5 percent of polymer admixture on the cement mass was almost 50 percent less than the shrinkage of the referent concrete.
- Pressure strains increased with the polymer-cement ratio.
- Adhesion between reinforcement and concrete increased with the polymer-cement increase.

(Ohama, 1998) used (SBR) polymer and found among the abilities that are affected by the addition of polymer is a concrete strength. The results indicated that there was a remarkable development in the bending and tensile strength, but there was no significant improvement in the compressive strength compared with normal concrete.

(Ohama, 1998) explained that the absorption of water for these concrete fog treatment is very slightly due to filling the pores with a polymer film, leading to the low permeability of this type of concrete.

2.5 High Strength Reinforced concrete:

Concrete is defined as "high-strength" based on compressive strength at a certain age only. Before the appearance of plasticizers in 1970, mixtures with compressive strength of 41 MPa or more at 28 days, called high-strength concrete. After that the mixtures with compressive strength 60 to 120 MPa became more common. In 2010 ACI committee considered the mixtures of strength design of 55 MPa and above is a high-strength concrete ***(ACI Committee 363, 2010, Mehta, 1986)***. A mixture of compressive strength exceeding 50 MPa can be obtained using any type of ordinary Portland cement, but the cement used should be over 400 kg/m^3 and may sometimes reach 600 kg/m^3 or more . However, it is not desirable because of the high cost and excessive thermal send drying shrinkage. ***(Mehta, 1986)***.

(Gjørv, 2008) stated that an early stage, high-strength or high-performance concrete was mostly applied to high-rise buildings, bridges and offshore structures, but it was successively applied to a variety of other applications such as:

- Harbour and coastal structures.
- Hydraulic structures.
- Underground construction.
- Pavements and industrial floors.
- Water treatment plants.
- Storage facilities for aggressive waste and chemicals.

It is necessary to use admixtures in combination with cement to obtain a higher strength while keeping good workability ***(Mehta, 1986)***. According to ACI 116R and ASTM C 125, admixtures are ingredients other than water, aggregates, hydraulic cement, and fiber that are added to the concrete batch immediately before or during mixing ***(Duggal, 2009)***. A proper use of admixtures offers certain beneficial effects to concrete, including acceleration or retardation of setting time, improve concrete strength and durability, as well as improve workability and finish ability. Basically, two categories of admixtures are available: mineral and chemical admixture ***(Kosmatka et al., 2002, ASTM/C125-03, 2009, ACI, 1980)***.

Superplasticizer admixture is a type of high range water reducing chemical admixture, which has a capacity of reducing the mixing water up to 35%. This type of admixture will provide a high-quality improvement for concrete in both fresh and hardened states. Generally, superplasticizer admixtures improve workability, strength, and permeability of concrete ***(Ramachandran, 1996).***

The reduction in water caused by water reducing agents results in a net increase in strength at 28 days. When high range water reducing admixtures are used by decrease the w/c, the 28-day compressive strength can increase by 20% or more. This seems to be related to the greater degree of hydration at later ages caused by these admixtures and hence leads to a higher strength even at the same water-cement. The increase in mechanical properties (i.e., compressive and flexural strength and modulus of elasticity) is achieved with reductions in the water-to-cement ratio ***(Ramachandran, 1996, ACI, 1980, ACI Committee 363, 2010, ASTM/C494, 2001, Leta, 2014).***

(Leta, 2014) investigated the effect of superplasticizer admixture (Mega Flow SP1) on concrete properties, such as workability, strength (compressive and flexural) and permeability . The results obtained from the study are:

- The percent of 1.5 superplasticizer admixture added to the concrete mix can provide a significant change on workability.
- The addition of superplasticizer admixture in the concrete mix by reduction of the equivalent amount of water as the amount of superplasticizer admixture added has shown a slight variation on compressive strength than the reference concrete.

- it is possible to reduce 5.92%, 7.66% and 11.25% of the mixing water from concrete by the addition of 0.5%, 1% and 1.5% of the superplasticizer admixture, respectively, at a constant workability.
- The addition of the superplasticizer admixture to the concrete improves compressive strength, flexural strength and the resistance to water penetration. Increment up to 26.96%, 27.3%, and 52.3% was observed for compressive strength, flexural strength, and the resistance to water penetration, respectively at a 1.5% superplasticizer admixture.
- It is possible to save 16.72kg/m^3, 19.13kg/m^3 and 26.97kg/m^3 of cement by the addition of 0.5%, 1% and 1.5% superplasticizer admixture at the same workability, water to cement ratio and strength, respectively.

2.6 Behavior of Reinforced Concrete Members under Compression:

Concrete is from a structural point of view, assumed to be a no-tension material with some softening post-peak behavior in compression due essentially to the limited transverse strain capability of the material. This characteristic influences the structural performance of reinforced concrete structures because the mechanical behavior of plain concrete is essentially brittle ***(Bencardino et al., 2008).*** *Fig. (2-6)* presents typical stress-strain curves obtained from concrete cylinders loaded in uniaxial compression in a test conducted over several minutes. The curves are almost linear up to about one-half the compressive strength. The peak of the curve for high strength concrete is relatively sharp, but for low strength concrete, the curve has a flat top. At higher strains after the maximum stress is reached, stress can still be carried even through cracks parallel to the direction of the loading become visible in the concrete. Concrete tested inflexible testing machines sometimes fails explosively because the concrete cannot absorb the release in strain energy from the testing machine when the load decreases after maximum stress ***(Park and Paulay, 1975).***

Tests by Rüsch ***(Rüsch, 1955)*** have indicated that the shape of the stress-strain curve before maximum stress depends on the strength of the concrete, see *Fig. (2-7)*. However, a widely used approximation for the shape of the stress-strain curve before maximum stress is a second-degree parabola.

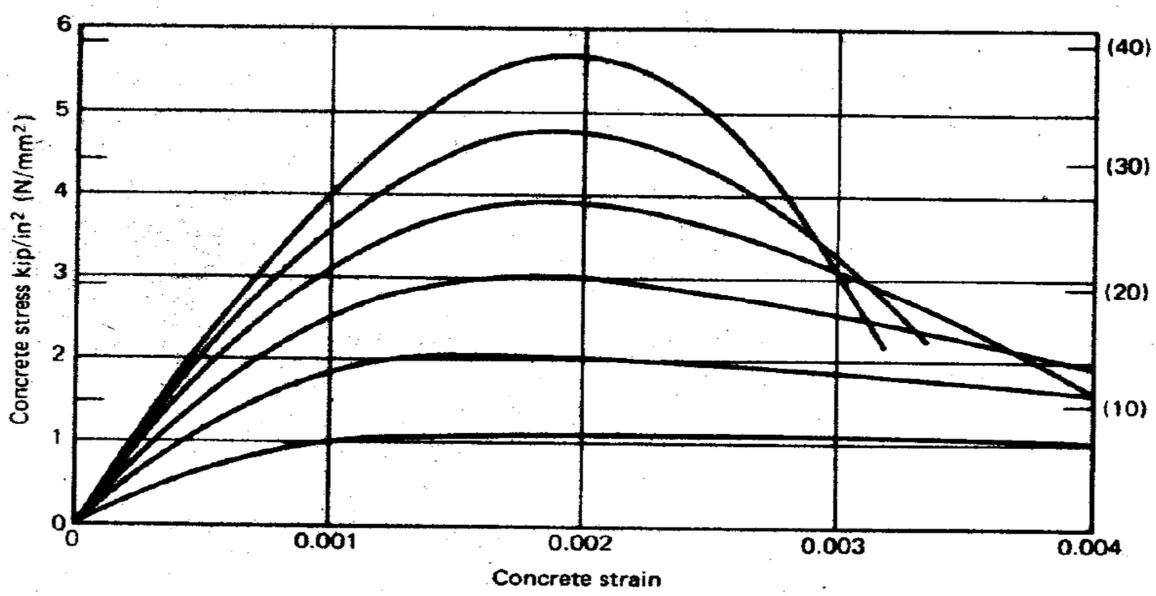

Fig. (2-6): Stress- Strain curves for concrete cylinders loaded in uniaxial compression ***(Park and Paulay, 1975)***.

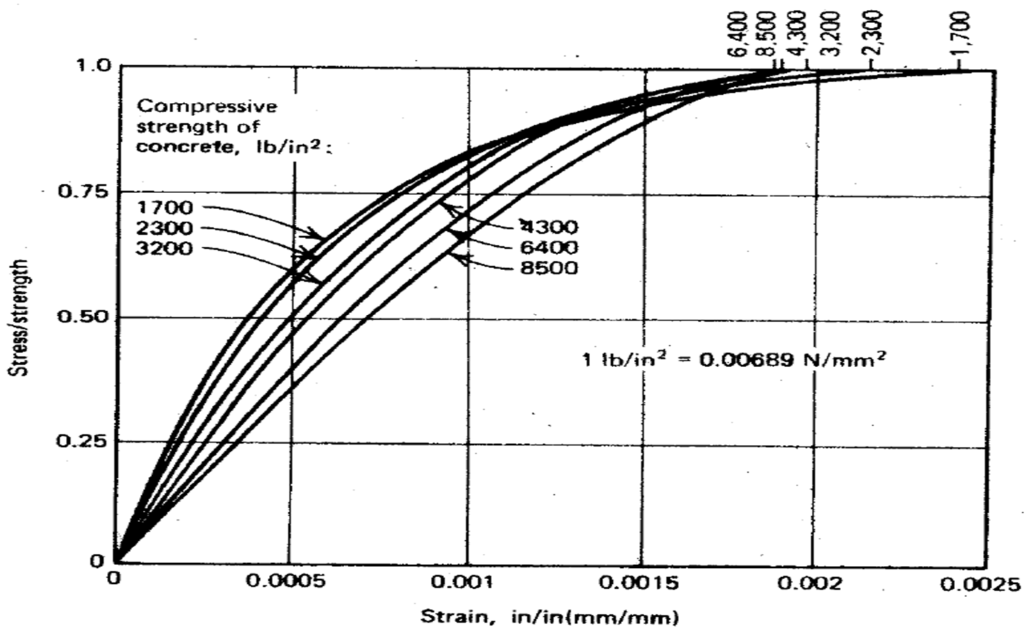

Fig. (2-7): Relationship between the stress to strength ratio and strain for concrete of different strengths ***(Rüsch, 1955)***.

The ratio between the transverse strain and the strain in the direction of the applied uniaxial loading referred to as Poisson's ratio. At high compressive stresses, the transverse strains increase rapidly, owing to internal cracking parallel to the direction of loading within the specimen. Strains measured in a specimen tested to the failure are plotted in *Fig. (2-8)*. During most of the loading range the volume of the specimen decreases, but at high stresses near the compressive strength of the specimen, the transverse strains become so high that the volume of the specimen will actually commerce to increase, indicating the breakdown of strength. The failure of a tied column loaded uniaxially in compression is generally accompanied by splitting in the direction parallel to the load and volume increase ***(Park and Paulay, 1975).***

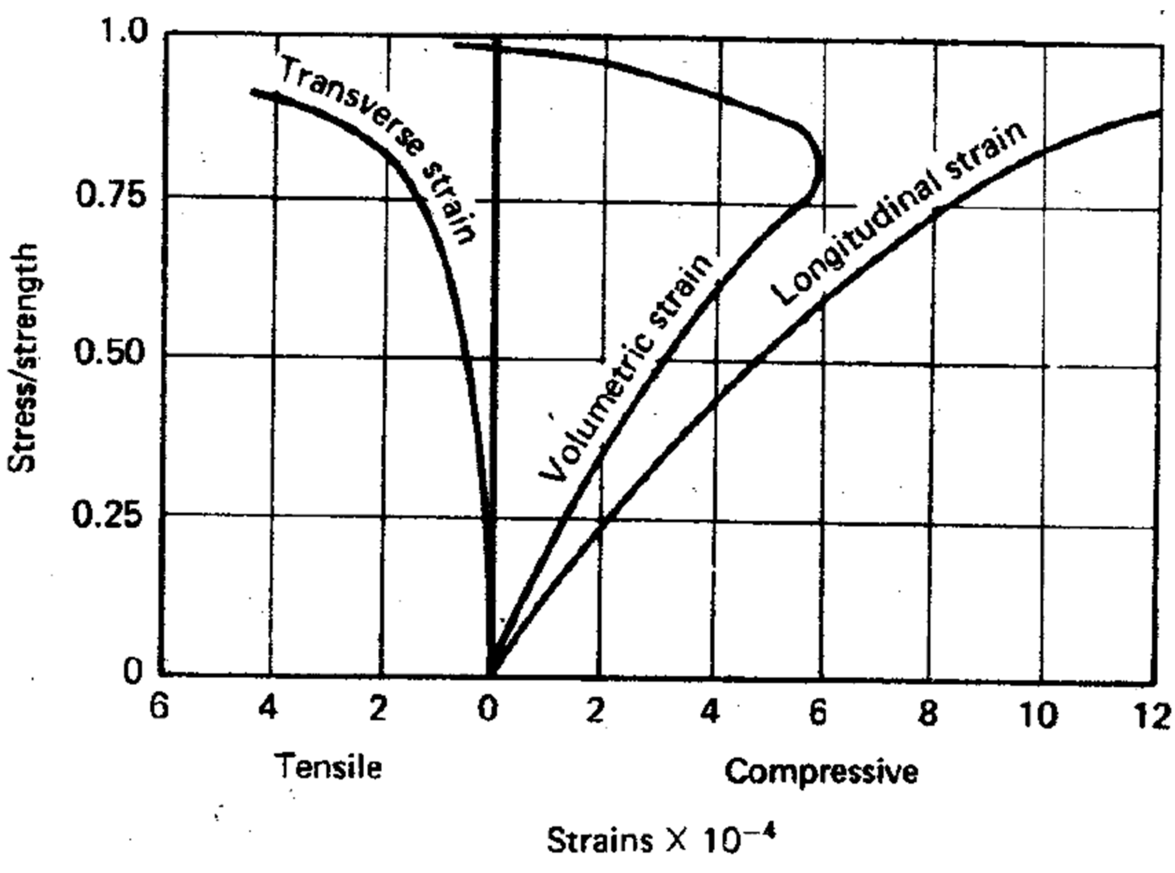

Fig. (2-8): Strains measured in a concrete tied column loaded uniaxially in compression ***(Park and Paulay, 1975).***

In practice, concrete may be confined by transverse reinforcement, commonly in the form of closely spaced steel spirals or hoops. The confinement becomes more effective at stresses approaching the uniaxial concrete strength, where the transverse strains become very high because of the progressive internal cracking and the concrete bears out against the transverse reinforcement which then applies a confining reaction to the concrete and it becomes confined. Many experimental studies conducted by several researchers showed that such confinement can considerably improve the stress-strain characteristics of concrete at high strain levels. The increase in strength and ductility with the content of confining steel is very significant ***(Tapan, 2007).***

An increase in column strength and ductility was observed through the good distribution of longitudinal and closly spaced lateral reinforcement in columns, as shown in *Fig. (2-9)*.

It is found that the ductility of high strength columns can be improved using lateral reinforcement ***(ACI Committee 363, 2010)***.

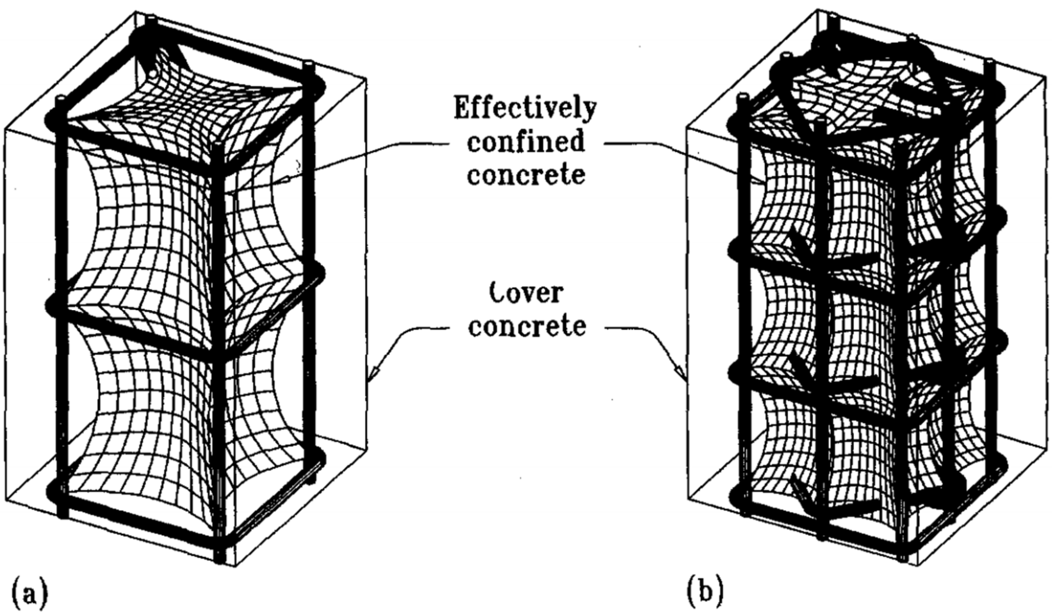

Fig. (2-9): Effects of Tie Configuration and Spacing on Confined Concrete Core: ***(a)*** *Poor Tie Configuration with Large Tie Spacing;* ***(b)*** *Good Tie Configuration with Small Tie Spacing* ***(Cusson and Paultre, 1994)****.*

The stress level in the transverse reinforcement at a peak strength of confined concrete does not necessarily reach the yield stress ***(Cusson and Paultre, 1995).*** High strength concrete exhibits less lateral expansion under axial compression than normal strength concrete due to its higher modulus of elasticity and its lower internal micro cracking. Consequently, the confining reinforcement comes into play later in the process and the efficiency of passive confinement of high strength concrete would be reduced ***(Cusson and Paultre, 1994).***

(Cusson and Paultre, 1994, Saatcioglu and Razvi, 1998, Sharma et al., 2005) found a sudden separation of the concrete cover in the high-strength concrete columns in the weakness areas resulted from the existence of a steel bar. Early cracking occurred in the concrete cover due to the loss of axial capacity of the column before the effect of lateral reinforcement began. After the good coverage of the concrete column, early cracking stopped and there was an increase in strength, ductility and toughness. From this, it is concluded that only the core area is used to calculate the axial compressive strength of the high-strength concrete columns unless other considerations are applied to separate the concrete cover.

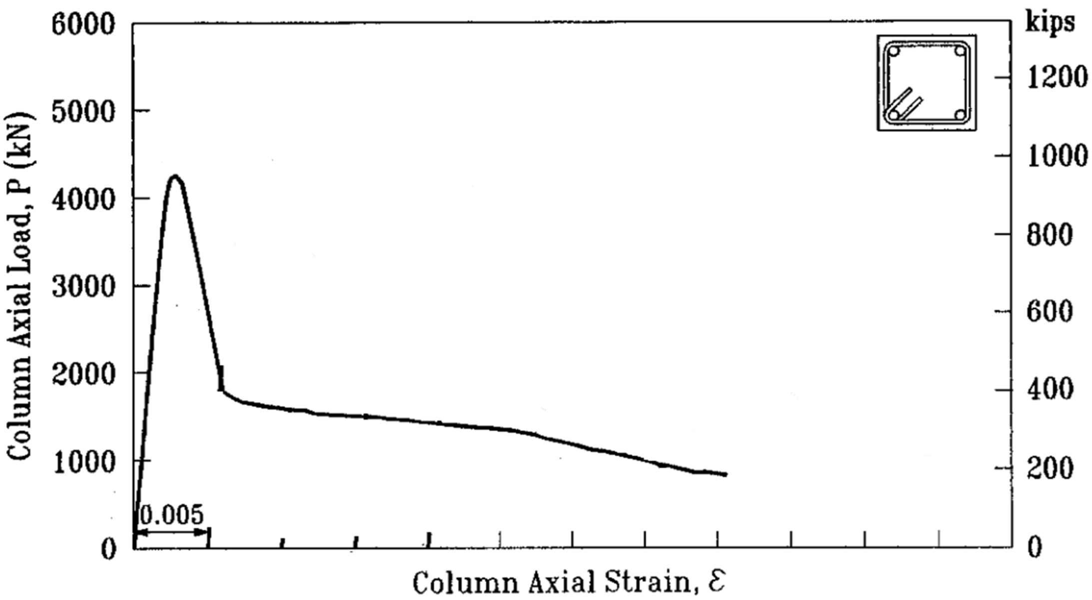

Fig. (2-10): Total Load versus Axial Strain Curves for Test Specimens ***(Cusson and Paultre, 1994).***

High strength concrete columns under monotonically increasing concentric compression show extremely brittle behavior unless confined with transverse reinforcement that can provide sufficiently high lateral confinement pressure. There is a consistent decrease in column deformability with increasing concrete strength ***(Saatcioglu and Razvi, 1998)***.

2.7 Effect of Aggressive Solutions on Reinforced Concrete:

Sulfate attack is one of the most aggressive environmental deteriorations that affect the long-term durability of concrete structures. Sulfate attack of concrete leads to expansion, cracking, and deterioration of many civil engineering structures exposed to sulfate environment such as piers, bridges, foundations, concrete pipes, etc. The sulfate ions in solution, which come from the soil, groundwater, and seawater, are found in combination with other ions such as sodium, potassium, magnesium and calcium ions ***(Brown, 1981)***.

The sulfate attack is generally attributed to the reaction of sulfate ions with calcium hydroxide and calcium aluminate hydrate to form gypsum and ettringite. The gypsum and ettringite formed as a result of sulfate attack are significantly more voluminous (1.2 to 2.2 times) than the initial reactants ***(Hooton, 1993)***.

The formation of gypsum and ettringite leads to expansion, cracking, deterioration, and disruption of concrete structures. In addition to the formation of enttringite and gypsum and its subsequent expansion, the deterioration due to sulfate attack is partially caused by the degradation of calcium silicate hydrate (C–S–H) gel through leaching of the calcium compounds. This process leads to loss of C–S–H gel stiffness and overall deterioration of the cement paste matrix ***(Mehta, 1983)***.

The shortened notation, used by cement chemists, describes each oxide by one letter; (C=CaO, S=SiO_2, A=Al_2O_3, M=MgO and N=Na_2O). Likewise, H_2O in hydrated cement is denoted by H and $\bar{S} = SO_3$.

The deterioration process of structures/building materials subjected to external sulfate attack occurs due to two types of attack; chemical attack and physical attack. Chemical attack is known as deterioration by ingression sulfate ions in reactions with cement hydration products leading primarily to the formation of ettringite and gypsum, whereas scaling of concrete as a result of sulfate salt crystallization in the pores of concrete is known as physical attack ***(Ghalib and Alaa, 2011)***. The sulfate attack chemical interaction is a complicated process and depends on many parameters including the concentration of sulfate ions, ambient temperature, cement type and composition, water to cement ratio, porosity, and permeability of concrete, and the presence of supplementary cementitious materials ***(Tumidajski et al., 1995)***.

(Scherer, 2004) thought that deterioration of attack occurs when concrete is in contact with soil, ground water may be drawn into its porous by capillary suction. Groundwater rises into the concrete at a rate that decreases with the height, while evaporation from the surface occurs at a nearly uniform rate. As water evaporates the salts concentration at drying surface continuously increases until the supersaturation is high enough to cause precipitation of salts, thereby crystals of salt precipitation will grow generating higher pressure that exceeds the tensile strength of the porous materials.

(Al-Amoudi, 2002) show that cement, counting the sulfate-resisting ASTM C 150 Type V ***(ASTM/C150, 1999)***, are exposed to sulfate attack. However, the intensity and percentage of attack depend on the following factors:

- **Cement type:** the most important stages of Portland cement that affect the concentration of sulfate attack in lessening order of rank are: C_3A, C_3S/C_2S ratio and C_4AF. ***(Mehta, 1981)***and ***(Lawrence, 1990)*** pointed out that increasing the content of C_3A in the cement composition was very effective in decreasing steel corrosion, but resulted in the lower resistance for sulfate attack.

- **Sulfate type and concentration:** The procedure associated with $SO4^{=}$ has an important effect on the deterioration of concrete, although this deterioration increases with increasing concentration of sulfate to a certain extent. American Concrete Institute ***(ACI318M-14, 2014)*** classifies the severity of sulfate attack as related to concentration of sulfates as $SO_4^{=}$ in a solution extracted from groundwater, see *Table (2-4).:*

*Table (2-4): Classification of severity of sulfate according to **(ACI318M-14, 2014)***

Sulfate exposure	*Water-soluble sulfate (SO4) in soil, percent by mass*	*Dissolved sulfate (SO4) in water, ppm*
Negligible	< 0.10	< 150
Moderate	0.10 - 0.2	150 - 1500
Severe	0.2 - 2.0	1500 -10,000
Very severe	> 2.0	> 10,000

According to British Standards ***(BS5328:Part1, 1997)*** there are five classes of concrete exposed to external sulfate attack from groundwater, as shown in *Table (2-5):*

*Table (2-5): Classification of severity of sulfate according to **(BS5328:Part1, 1997)***

Class	*SO_4 in groundwater (g/l)*	*SO_4 in Soil (g/l)*
1	< 0.4	< 1.2
2	0.4 - 1.4	1.2 - 2.3
3	1.5 - 3.0	2.4 - 3.7
4A	3.1 - 6.0	3.8 - 6.7
4B	3.1 - 6.0	3.8 - 6.7
5A	> 6.0	> 6.7
5B	> 6.0	> 6.7

When results are expressed as SO_3 they may be converted to SO_4 by multiplying by a factor of 1.2 ***(Marchand et al., 2003)***.

For the Iraqi specifications SO_3 must not to exceed 5% in accordance with British Standard ***(BS1377-3, 1990)*** test NO. 9

- **Water/cement ratio** is the most critical parameter influencing the resistance of concrete to sulfate attack because the degradation of concrete is associated with its permeability which is inversely related to the w/c. The lower water content, less attack to sulfates by justifying the distribution of $SO4^{=}$ ions into mixes ***(Prasad et al., 2006).***

(Boyd and Mindess, 2004) discussed the effect of water to cement ratio and cement type on the resistance of concrete to sulfate attack. The water to cement ratio (0.45 and 0.65) and cement type (ordinary and sulfate resistance) were investigated. The results indicated that the use of a lower w/c appears to be far more effective than the use of sulfate resistant cement in offsetting the detrimental effects of sulfate attack on concrete. Not only are the benefits of using sulfate-resistant cement type less evident than those produced by a lower w/c ratio, there is also a significant drop in strength associated with high w/c ratio

- **The presence of Chloride with Sulfate:** The chloride ions are inadvertently associated with sulfate in the attack of groundwater or marine environment on concrete. Chloride reacts with the hydrates of cement and forms Freidel's salt that does not have any harmful effects on concrete, but when chloride content in concrete reaches more than the threshold value, the protective alkaline layer of steel reinforcement is broken, and in the presence of oxygen and humidity steel reinforcement gets corroded. The presence of chloride in sulfate solution affects the deterioration of concrete under sulfate attack, as shown in *Fig. (2-11)* ***(Prasad et al., 2006).***

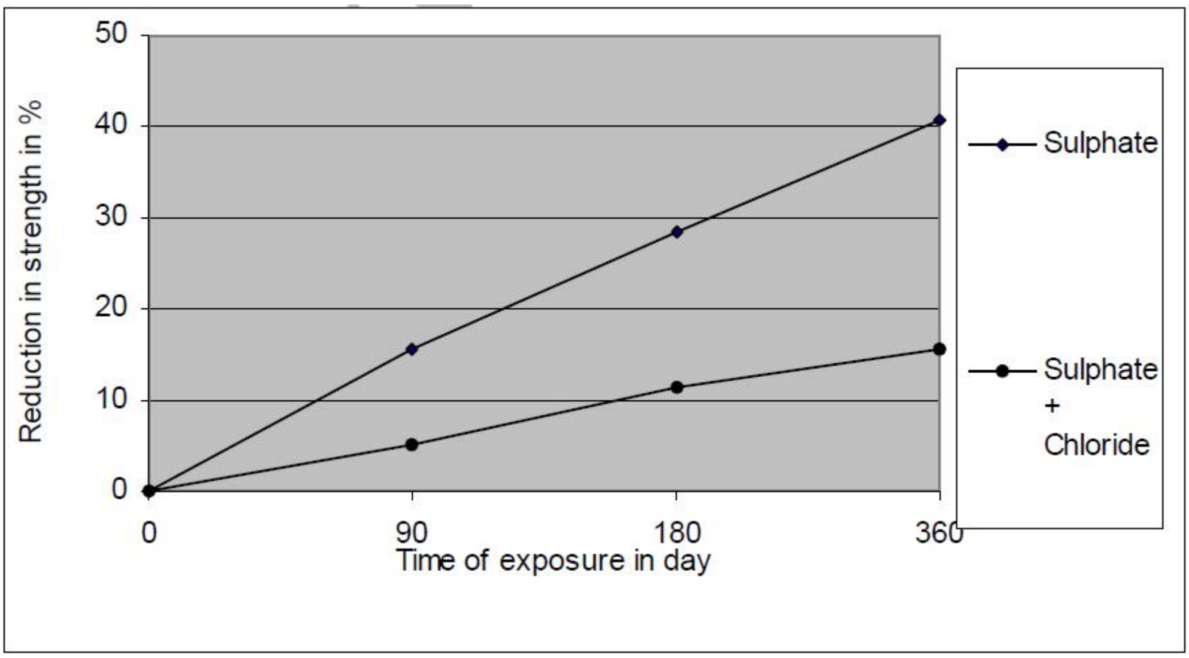

Fig. (2-11): Effect of chloride presence in sulfate solution ***(Prasad et al., 2006)***

- **The quality of concrete:** it is the most important factor influncing the durability of concrete in general and sulfate resistance in particular. Since impermeability always reflects the quality and durability of concrete, sulfate attack, particularly the type of degradation associated with sodium sulfate, is inversely related to the concrete quality, i.e., dense concrete tends to resist sulfate attack more than permeable concrete. In magnesium sulfate environments, however, the cement type dominates the extent of sulfate attack compared to the denseness of concrete, especially at the surificial layers of concrete ***(Al-Amoudi, 2002)***.

The chemical resistance of latex-modified mortar and concrete is dependent on the nature of polymers added, polymer-cement ratio and the nature of the chemicals. Most latex modified mortars and concretes are attacked by inorganic or organic acids and sulfates since they contain hydrated cement that is non-resistant to these chemical agents, but resists alkalis and various salts except the sulfates. Their chemical resistance is rated as good to fats and oils, but poor to organic solvents ***(Su, 1995, Ohama, 1995).***

Shaker ***(Shaker et al., 1997)*** has investigated and evaluated the main durability features of polymer concrete (SBR) compared to normal concrete. The polymer concrete showed at the different test ages a decrease about 36% to 47% in weight loss compared with the normal concrete. Also, the polymer concrete showed at different test ages a decrease about 41% to 50% in a dimensional loss compared with the normal concrete. The growth in the corrosion time with test age was about 23.9% for the polymer concrete, while it was only about 4.2% for the normal concrete. The increase in time of corrosion in the polymer concrete indicates that the polymer concrete is the best protection for reinforcing steel against corrosion of ordinary concrete, and this protection is improved with age. The pattern of cracking in polymer concrete was different from that in ordinary concrete. In polymer concrete it was slow and multi-directional, whereas in conventional concrete it was fast-long crack. This difference in behavior may be due to high tensile strength in polymer concrete and good bonding between aggregates and polymer cement mix. Polymer concrete showed a decrease in compressive strength less than normal concrete after immersion in the sulfate solution. This indicates that polymer concrete is better than the normal concrete in the sulfate resistance, as shown in *Fig. (2-12).*

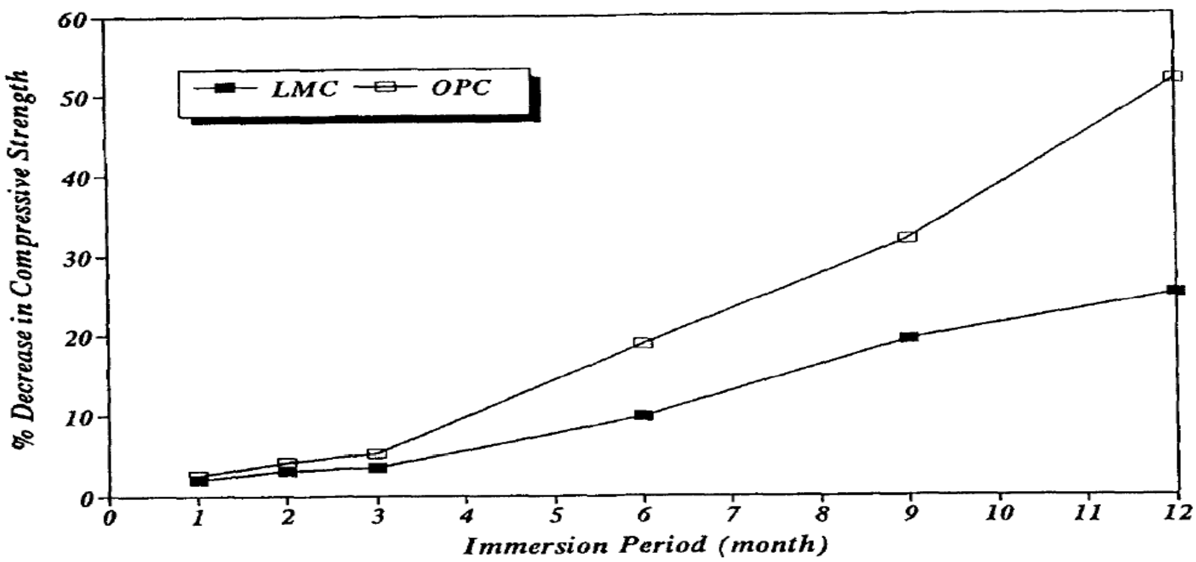

Fig. (2-12): Percentage decrease in compressive strength after different immersion periods for polymer and normal concrete. ***(Shaker et al., 1997)***

2.8 Properties of Soils and Groundwater in Karbala City:

The geotechnical investigation for different sites in Kerbala have been collected. The purpose of the investigation was to determine the surface and subsurface conditions of the sites including the physical, chemical and mechanical properties of subsurface ground materials, as well as to assess chemical properties of the soil and groundwater in Kerbala.

2.8.1 SITE ONE (Al-Ataba Al-Abasiyah Divisions Building Project):

The project site is located inside the old city near Imam Abbas Holy Shrine.

Plate (2-1): Location of Al-Ataba Al-Abasiyah Divisions Building Project.

2.8.1.1 Ground Materials:

The drilled boreholes showed general similarities and continuities of the subsurface materials. The main soils in the profile are clayey sand and high to low plasticity clay with some sand and silt. Three ground material types were distinguished, clayey sand, clay and silty sand.

2.8.1.2 Physical & Mechanical Properties:

The field and laboratory test results, as well as the corresponding material classifications for the various ground materials, are summarized in *Table (2-6):*

Plate (2-2): Selected pictures describe type of soil for Al-Ataba Al-Abasiyah site.

Table (2-6): Summary of Physical Test Results for Al-Ataba Al-Abasiyah Site

Depth (m)	WC%	Gs	γ kN/m^3	LL%	PL%	PI%	Passing #200%		Sand %	Gravel %	USCS	Color	Moisture condition	Description
							Clay%	Silt%						
0														Clayey Sand
1.5	27.19	2.79	21.34				11.35	30.74	44.78	13.12	SC	Gray	Moist	
2	29.09											Gray	Moist	
3.5	35.63			47.6	35.58	12.02						Gray	Wet	
4	34.85			52.76	22.69	30.07						Gray	Wet	
5.5	31.39	2.72	18.81	55.8	32.86	22.94						Gray	Moist	Clay with high plasticity
7.5	46.31			51.4	26.5	24.9	8.76	91.24	0.00	0.00	CH	Gray	Wet	
8	33.18	2.65										Gray	Wet	
9.5	38.81			55.4	20	35.4						Gray	Moist	Clay with high plasticity
11.5	37.70			51.2	8.89	42.31	22.86	77.14	0.00	0.00	CH	Gray	Moist	
12	18.81	2.60										Gray	Moist	
13.5	45.20											Gray	Moist	
15	31.75											Gray	Wet	Poorly graded Sand-Clayey Sand
16.5	43.81	2.73										Yellow	Wet	
18	28.66	2.08	20.42									Yellow	Wet	
19.5	33.00											Yellow	Moist	
21	29.03	2.66	20.17				8.76		87.74	3.49	SP-SC	Yellow	Moist	
22.5	33.41		19.68				1.57		93.25	5.18	SP	Yellow	Wet	Poorly graded Sand
24	33.75											Yellow	Moist	Clayey Sand
25	36.15	281		46.46	22.69	23.77	43.09		55.04	1.87	SC	Yellow	Moist	

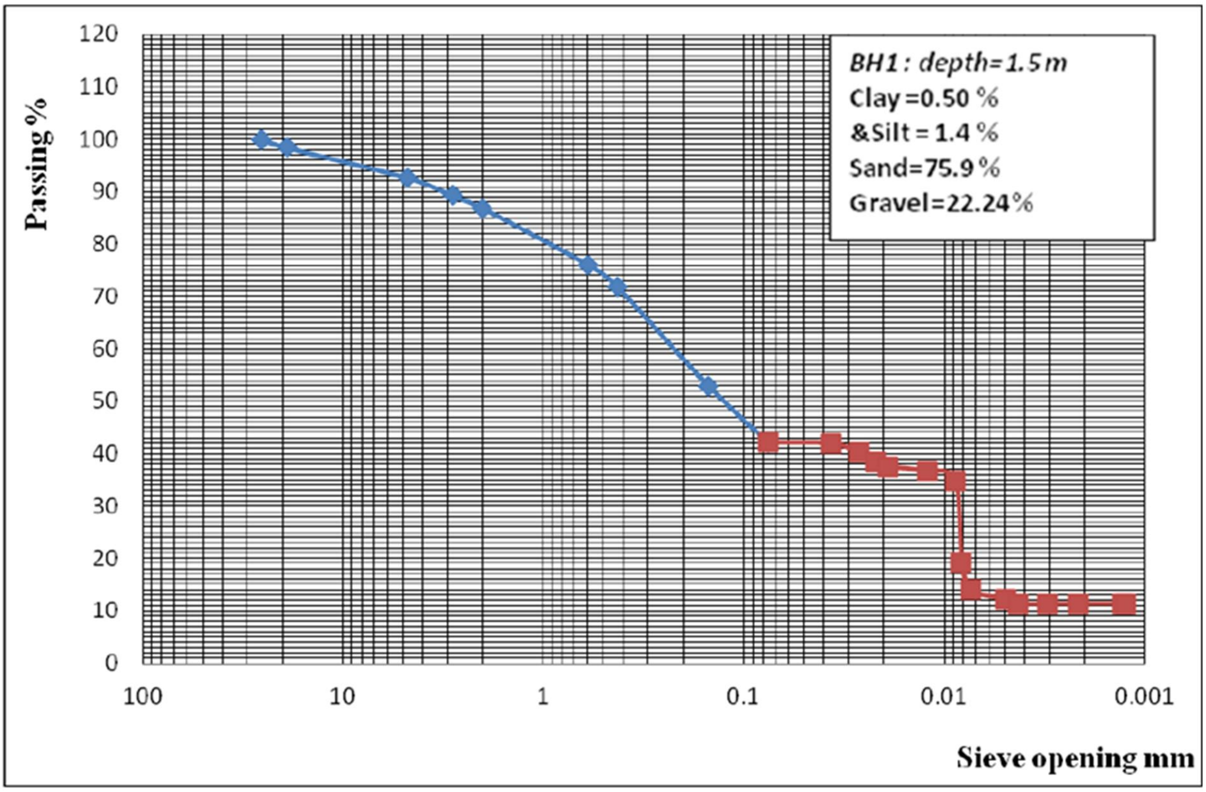

Fig. (2-13): Sieve analysis tests results for Al-Ataba Al-Abasiyah site.

2.8.1.3 Chemical Properties:

The laboratory chemical tests results are taken for different depths for each test. The level of PH for the soil water extracts greater than 7 and less than 10 for all samples (7.4 to 9.95), thusthe soils are slightly alkaline. The organic contents (O.M.%) are from (2.536 to 17.603%). The sulfate content (SO_3%) ranged from (0.067 to 9.189 %). This content may be a danger on the concrete of foundation, therefore, the procuring must be taken by using sulfate resistance cement. The sulfate content falls within the class (3) as categorized in BS 5328: Part-1 ***(BS/5328-1, 1997).*** The total dissolved salt varied from (0.49 to 15.745 %) , while the gypsum content ranged from (0.144 to 19.757%).

2.8.2 SITE TWO (Educational Hospital (600-Beds) for Kerbala University):

The site located about (1.0) Km from Kerbala - Hilla road in Frayha district opposite to Kerbala University.

2.8.2.1 Ground Materials:

According to the Unified Soil Classification System (USCS), the subsoil profile can be summarized as follows:

- The upper layer is filled material (clayey silty sand & sandy silty clay) with pebbles, organic material & gypsum down to about (2.0 to 2.5) m below G.S.
- The next layer is brown, black to grey soft to hard sandy silty clay with iron oxide-organic material and gypsum down to about (12.0 to12.5) m below G.S. This layer contains a thin layer of brown, black and grey loose to medium clayey silt sand (River Sand) about (0.5 to 2.5) m thick.
- The last layer is brown red, gray and black medium to very dense fine to coarse sand and clayey silty sand with iron oxide, gypsum, and pebbles each extends down to the ends of borings.

The groundwater level was encountered at a depth varying from 1.0 m to 1.25m below the ground surface (G.S.).

2.8.2.2 Physical & Mechanical Properties:

The field and laboratory tests results, as well as the corresponding material classifications for the various ground materials are summarized in *Table (2-7)*. The results indicate that the natural moisture content is closer to the plastic limit than to the liquid limit, this trend suggests that the cohesive layer is overconsolidated with soft to hard consistency.

Table (2-7): Summary of Test Results for Hospital Site

Samples		Depth of sampling (m)		Index properties			Particle size distribution &Hydrometer analysis				SP. GR. (GS.)	S.P.T (N) Value	Symbol Uni. Class	Description of soil
							% pass. by wt. from sieve no.							
							4	10	40	200				
Filed	Type	From	To	M.C.%	L.L%	P.L%	Clay%	Silt%	Sand %	Gravel %				
1	SS	2.5	3.0		62.1	30.9						18	CH	Brown Hard Silty Clay + Iron Oxide
2	U	5.5	6.0	24 21.2			(6	29	65	0)	2.65	-		Brown Silty Sand (River Sand)
3	SS	6.0	6.5				(24	32	44	0)	2.67	13		Brown Medium Clayey Silty Sand
4	U	9.0	9.5	36.96 34.1			(64	27	9	0)	2.75	-		Brown, Grey Soft Silty Clay + Organic Material
5	SS	9.5	10.0		54.9	27.3						10	CH	Brown Stiff Silty Clay
6	U	12.5	13.0	31.0 34.6			(11	24	65	0)	2.65	-		Pale Brown, Grey Clayey Silty Sand
7	SS	13.0	13.5				(17	20	60	3)	2.65	19		Do (Medium) + Gypsum
8	SS	16.0	16.5				(11	19	70	0)	2.65	-		Do
9	SS	19.0	19.5				(6 -		93	1)		58		Brown Very Dense Silty Sand + Pebbles
10	SS	22.0	22.5				(8 -		87	5)		42/6”		Do + Do
11	SS	25.0	25.5				(29 -		71	0)		>50		Red very Dense Clayey Silty Sand
12	SS	28.0	28.5				(18	21	55	6	2.65	>50		Do + Gravel
13	SS	31.0	31.5				(10 -		84	6)		25		Brown Medium Silty Sand + Pebbles
14	SS	33.0	33.5									32		Do + Do
15	SS	35.5	36.0				(17 -		83	0)		>50		Do (very Dense)
16	SS	36.5	37.0				(9 -		58	33)		>50		Do (Black) + Gravel

2.8.2.3 Chemical Properties:

The results of the chemical tests for the soil and water indicate highly sulfate content. For soil samples, the sulfate content (SO_3 %) varies from (0.26 to 8.725) %, whereas this content may be a danger on the concrete of foundation, therefore, the procuring must be taken by using sulfate resistance cement. The sulfate content falls within class (3) as categorized in BS 5328: Part-1 ***(BS/5328-1, 1997)*** and the chloride content (CL^- %) varies from (0.0177 to 0.0712) %. The gypsum content varies from (0.56 to 18.76) %. The total soluble salts content varies from (0.6 to 19.1) %. The Organic material content (O.M. %) varies from (0.41 to 2.03)%, and PH content varies from (7.9 to 9.57), therefore the soils are slightly alkaline. For water samples, the sulfate content varies from (334.93 to 379.8) mg/L, and the chloride values vary from (3.46 1 to 5.172) where (PH) content is (8.2).

2.9 Concluded Remark:

According to the previous review, it is required to investigate the behavior of reinforced concrete element exposed to an aggressive solution. A reinforced concrete column is chosen in this study according to its importance and due to the limited study in this area. An attempt should be due to improve the microstructure of concrete using some types of admixtures.

Chapter Three

Experimental Work

CHAPTER THREE

Experimental Work

3.1 General:

This chapter contains detailed of discussion regarding the properties of materials, which have been used in the experimental work, mixes, mix procedure, casting, curing, different testing procedures, and details of the column specimens.

The intent of this work is to find the effect of sulfate from different types of soil and groundwater on three types of reinforced concrete; (normal, polymer, and high-strength reinforced concrete).

The slump test was done for all mixes in their fresh state, while axial compressive test of the studied columns, compressive strength, splitting tensile strength, absorption, voids content, and density tests have been performed for specimens after casting, then cured and buried in soils up to the tested age. The main details of this experimental work are shown in *Fig. (3-1)*.

3.2 Materials:

The following subsections provide information about the materials used in the present work.

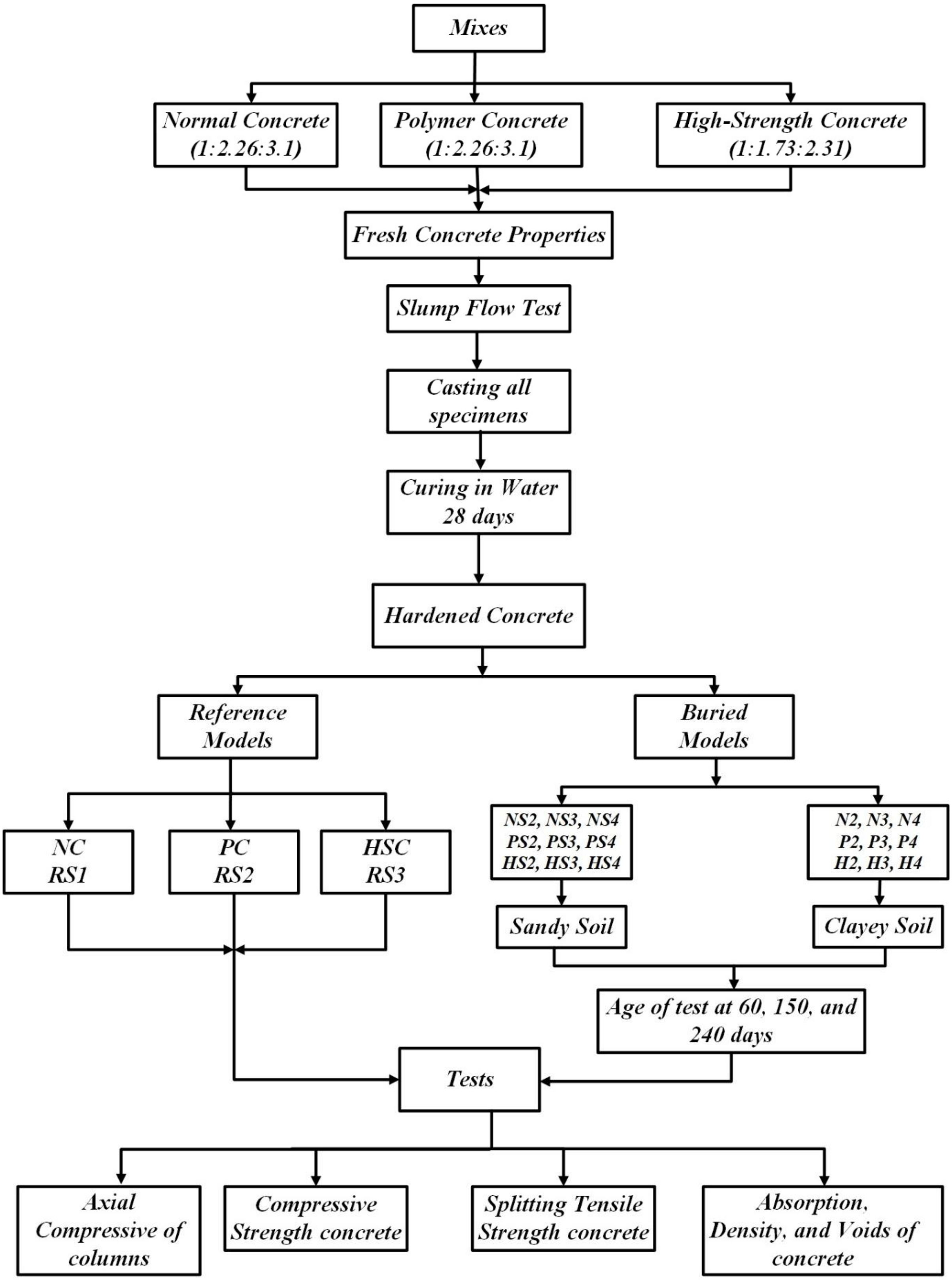

Fig. (3-1): Details of the experimental program

3.2.1 Cement:

In this research, sulfate-resisting Portland Cement (ASTM - Type V) ***(ASTM/C150, 2005)*** manufactured by United Cement Company commercially known (AL-GESR) was used. The chemical composition and physical properties of this Portland cement are given in *Tables (3-1) and (3-2)*, respectively. Test results indicate that the adopted cement conforms to Iraqi Specifications No.5/1984 ***(Iraqi/Specification).***

*Table (3-1): Chemical composition and main compounds of cement**

Compound composition	***Chemical composition***	***Percentage by weight***	***Limits of (IQS NO.5 /1984)***
Lime	CaO	61.46	/
Silica	SiO_2	20.91	/
Alumina	Al_2O_3	4.14	/
Iron oxide	Fe_2O_3	4.71	/
Sulfate	SO_3	2.13	$\leq$ 2.5 % If C_3A < 5% $\leq$ 2.8 % If C_3A > 5%
Magnesia	MgO	2.86	$\leq$ 5 %
Loss on ignition	L.O.I.	2.72	$\leq$ 4 %
Insoluble residue	I.R.	0.54	$\leq$ 1.5 %
Lime saturation factor	L.S.F.	0.90	0.66 – 1.02
Main compounds (Bogue's Equs.)		***Percent by weight of cement***	***Limits of (IQS NO.5 /1984)***
Tricalcium silicate (C_3S)		54.874	/
Dicalcium silicate (C_2S)		20.513	/
Tricalcium aluminate (C_3A)		3.003	$\leq$ 3.5 %
Tetracalcium aluminoferrite (C_4AF)		14.333	/

*Chemical tests were conducted by the environmental laboratory in Construction laboratory of Karbala.

*Table (3-2): Physical Properties of Cement**

Physical properties	***Test results***	***Limits of (IQS NO.5 /1984)***
Setting time (Vicat's Method) Initial, mints Final, mints	 125 275	 ≥ 45 min ≤ 600 min
Fineness (Blaine Method), m^2/kg	335	≥ 250 m^2/kg
Compressive strength, MPa 3 days 7 days	 29 36	 ≥ 15, MPa ≥ 23, MPa
Autoclave expansion, %	0.01	≤ 0.8

*Chemical tests were conducted by the environmental laboratory in Construction laboratory of Karbala.

3.2.2 Fine Aggregate:

The fine aggregate used in this work was from brought Al-Ekadir region. several laboratory tests were carried out in the constructional materials laboratory in university of Kerbala. Results show that to the properties of the fine aggregate meet the requirements of (IQS No.45/ 1984) ***(Iraqi/Specification)(3),*** as shown in *Tables (3-3), (3-4)* and *Fig. (3-2).*

Table (3-3): Fine aggregate gradation.

Sieve size (mm)	***Cumulative passing%***	***Limits of Iraqi Specification No.45/1984 /zone (2)***
10	100	100
4.75	96	90-100
2.36	78	75-100
1.18	61	55-90
0.6	47	35-59
0.3	18	8-30
0.15	5	0-10

*Table (3-4): Fine aggregate physical properties **

Physical properties	***Test result***	***Limits of Iraqi Specification No.45/1984***
Specific gravity	2.6	/
Fineness modulus	2.95	/
Absorption	0.75 %	/
Dry-Loose density (kg/m^3)	1595	/
Sulfate content	0.08 %	≤ 0.5 %
Material passing 75-micron sieve	1.7	< 5

*Physical tests were done by the constructional materials laboratory in University of Kerbala.

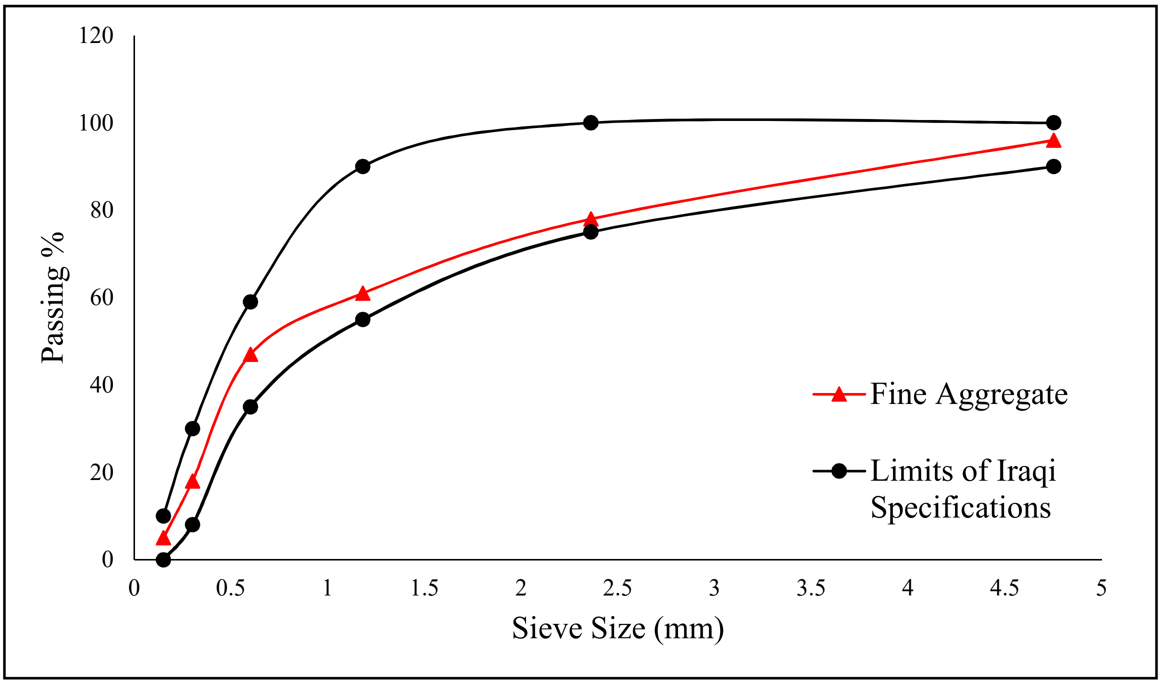

Fig. (3-2): Grading curve for fine aggregate

3.2.3 Coarse Aggregate:

Black crushed stones were used as coarse aggregate in all mixes with 20 mm maximum size brought from Al-Nebai quarry. *Table (3-5), (3-6)* and *Fig. (3-3)* show, test results of this aggregate which adapts to the Iraqi specification (IQS No.45/ 1984).

Table (3-5): Coarse aggregate gradation

Sieve size (mm)	***Cumulative passing%***	***Limits of Iraqi Specification No.45/1984***
75	/	/
63	/	/
37.5	100	100
20	97	95 - 100
14	/	/
10	33	60 - 30
5	4	0 - 10
Corrosion mechanical	16	/

*Table (3-6): Coarse aggregate physical properties **

Physical properties	***Test result***	***Limits of Iraqi Specification No.45/1984***
Specific gravity	2.65	/
Dry rodded density (kg/m^3)	1712	/
Absorption	0.9 %	/
Sulfate content	0.054 %	≤ 0.1 %
Material passing 75-micron sieve	0.1	< 3

*Physical tests were conducted by the constructional materials laboratory in University of Karbala.

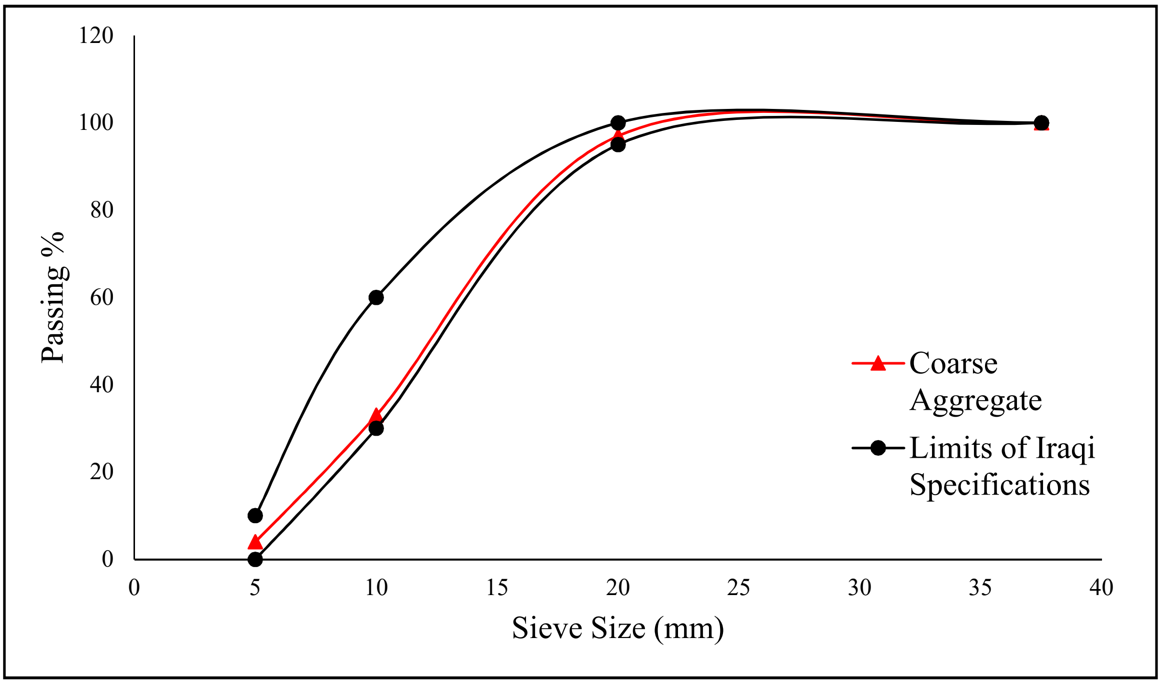

Fig. (3-3): Grading curve for coarse aggregate

3.2.4 Water:

Potable water from the water-supply network system was used for mixing and curing. It was free from suspended solids and organic materials, which might impair the properties of the fresh and hardened concrete.

3.2.5 Steel Reinforcement:

Turkish deformed steel bars (6 and 8) mm diameter were used as the rods of all column specimen's reinforcement used in this study. The steel reinforcement was tested according to ASTM-A615/A-615M-05a. The physical properties of steel bars are given in *Tables (3-7)*. *Plate (3-1)* shows the tensile steel testing machine.

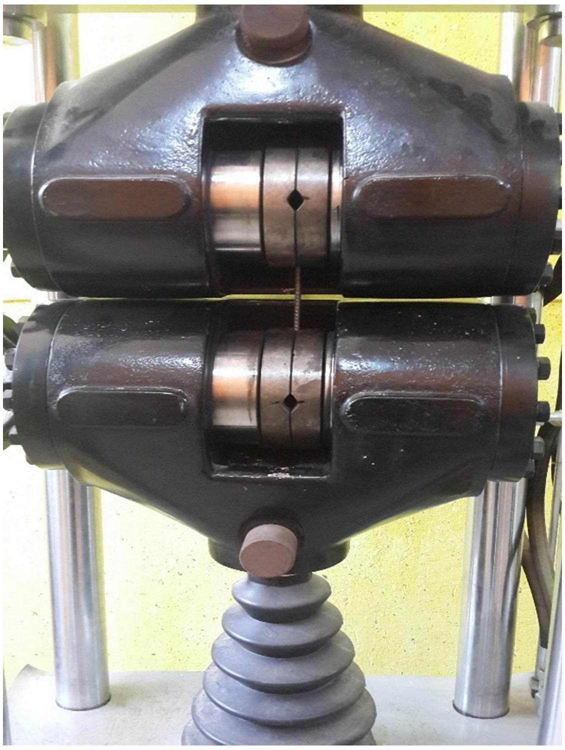

Plate (3-1): Photograph of tensile steel testing machine

*Table (3-7): Physical properties of steel bar**

Nominal dia. (mm)	Actual dia. (mm)	Area (mm^2)	Mass kg/m	Yield stress, fy (MPa)		Tensile strength, fu (MPa)		Es (GPa)	Elongation %
				Result	Limit	Result	Limit		
8	7.79	50.3	0.374	597.4	520	673.8	690	200	16.6
6	6	28.4	0.220	617.3	/	662.6	/	200	7.6

*Physical tests were done by the mechanical laboratory in University of Kerbala.

3.2.6 Superplasticizer:

To achieve the high strength concrete, (high range water reducers) Superplasticiser was used. The common superplasticizer used is a new generation type based on polycarboxylated polyether. Therefore, superplasticizer based on modified polycarboxylic ether, which is known commercially as Mega Flow 110 combined with Sika Rapid®-1 were used in this work.

Mega Flow 110 is a modified polycarboxylate ether based superplasticizer, see *Plate (3-2)*. It imparts effective dispersion between cement particles based on unique combination of electro static repulsion and steric hindrance. Due to its long chain polymeric structure, it exhibits superior performance compared to conventional superplasticizers. It complies with ASTM C494 Types A & F, BSEN 934-2. The typical properties of Mega Flow 110 are show in *Table (3-8),*

*Table (3-8): Typical properties of Mega Flow 110**

Properties	***Value***
Component	Single
Form	Liquid
Color	Opaque
Specific gravity	1.08 +/- 0.01
PH	5 – 7
Chloride Content	Nil

*From supplier

3.2.7 Sika Rapid®-1:

A new generation hardening accelerator for concrete and mortar, see *Plate (3-2).* It increases the early strengths of concrete without negatively influencing the final strength. Suitable for use in tropical and hot climatic conditions. It complies with BSEN 934-2. The typical properties of Sika Rapid®-1 are show in *Table (3-9).*

*Table (3-9): Typical properties of Sika Rapid®-1**

Properties	***Value***
Form	Reddish Liquid
Density	1.08 +/- 0.01
PH	Approximately 8.0
Chloride Content	Nil

*From supplier

3.2.8 Sika® Latex (SBR):

Sika® Latex is a modified styrene butadiene emulsion that is mixed normally with cement to form a bonding slurry, see *Plate (3-2)*. It can be also used as an additive to improve adhesion and water resistance properties of cement and sand mortar. The typical properties of Sika® Latex are show in *Table (3-10)*.

*Table (3-10): Typical properties of Sika® Latex (SBR)**

Properties	***Value***
Form	Liquid
Colour	Milky white
Density	Approx. 1kg/L
PH	Approx. 10
Solid Content	Approx. 47%

*From supplier

Plate (3-2): Superplasticizer and SBR admixture used in the present work

3.2.9 Soils:

Two types of soil have been used to bury the specimens and R.C columns models clayey soil and sandy soil. Two pits were excavated in an agricultural land located at (1.5 km) west of Karbala center. The pits' dimensions were (2×2×3) m. The reinforced concrete columns models and their related specimens were buried in the pits, then one pit filled with the sandy soil which has physical and chemical properties summarized in *Tables (3-11) and (3-15). Fig. (3-4) shows grain-size distribution of the sandy soil*. While the other pit was filled with the clayey soil which has physical and chemical properties shown in *Tables (3-12)* and *(3-15). Fig. (3-5) shows grain-size distribution of the clayey soil.* the groundwater level was about 1.5 m below the ground surface. The chemical properties of the groundwater are shown in the *Table (3-16). Plate (3-3) displays the pits and excavating work for the soils.*

Table (3-11): Grading of sandy soil.

Sieve size	***Opening (mm)***	***Passing %***
2″	50	100
1″	25	100
3/8″	9.5	77.2
No. 4	4.75	65.5
No. 8	2.36	55.2
No. 50	0.3	5.45
No. 200	0.075	0.65

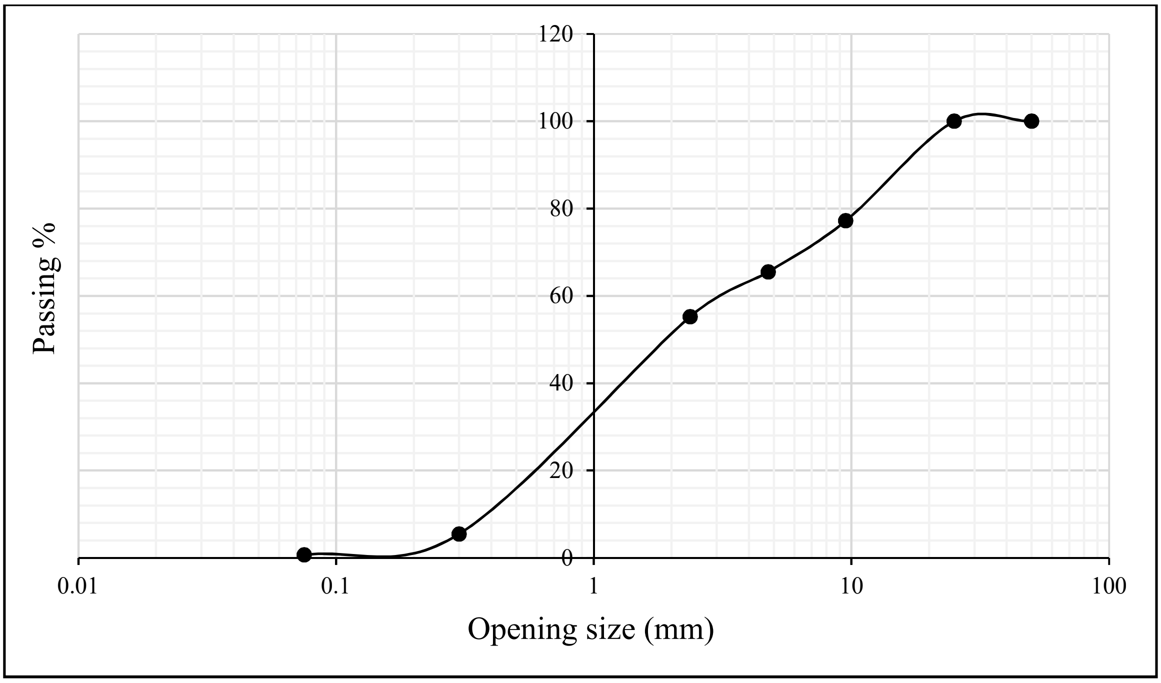

Fig. (3-4): Grain-size Distribution of sandy soil

Table (3-12): Grading of clayey soil.

Sieve size	***Opening (mm)***	***Passing %***
2″	50	100
1″	25	100
3/8″	9.5	100
No. 4	4.75	100
No. 8	2.36	95
No. 50	0.3	86
No. 200	0.075	73

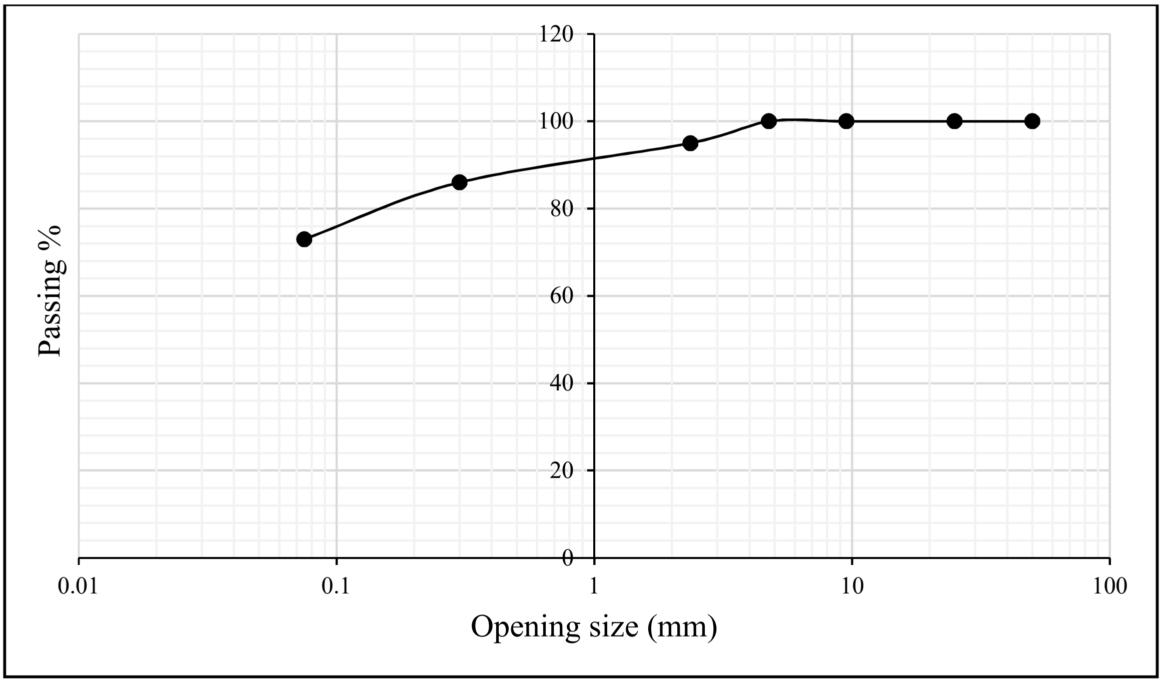

Fig. (3-5): Grain-size Distribution of clayey soil

Plate (3-3): Soil`s pits

3.3 Concrete Mixes:

To achieve the research objectives, three types of mixes were prepared according to ACI method after many trial mixes. Design work selected the best mixes based on the results that have been obtained from the laboratory tests including; slump test and compressive strength at age 28 days. *Table (3-13) and (3-14)* present the tests results of normal concrete mix without admixtures, polymer concrete, and high strength concrete. Admixtures, ((SBR) Sika Latex Modified Polymer, Mega Flow 110 and, Sika Rapid®1), were used as a percent by weight of cement. Details of the mixes used throughout this investigation are given in *Table (3-17).*

Table (3-13): Properties of trail mixes

Materials	**Normal**		**Polymer**		**High-strength**	
	Mix I	**Mix II**	**Mix I**	**Mix II**	**Mix I**	**Mix II**
Cement **(kg/m^3)**	336	336	336	366	420	420
Gravel **(kg/m^3)**	1044	1044	1044	1044	972	972
Sand **(kg/m^3)**	760	760	760	760	730	730
W/C	0.61	0.55	0.5	0.475	0.38	0.35
SBR %	/	/	5	7.5	/	/
SP %*	/	/	/	/	2.5+0.5	2+1.5

*Sp = (Sika rapid+Mega Flow 110)

Table (3-14): Compressive strength and slump values for trail mixes

Type of mix	**Mix No.**	**Compressive strength (MPa)**	**Slump (mm)**
Normal	Mix I	23	95
	Mix II	27.75	85
Polymer	Mix I	25.5	80
	Mix II	28.2	85
High-Strength	Mix I	40	90
	Mix II	46.15	85

Table (3-15): Physical and chemical properties for sandy and clayey soils.*

Soil Type	SiO_2%	Fe_2O_3%	Al_2O_3%	CaO%	MgO%	$SO_3^{=}$ %	LOI%	Na_2O%	K_2O%	Cl^-%	O.M%	PH	L.L%	P.L%	GS
Sandy	18.31	2.95	4.55	26.86	5.87	10.609	24.76	4.24	0.64	1.95	0.62	8.15	/	/	2.66
Clayey	33.79	6.40	12.43	12.49	7.79	2.61	18.02	2.20	1.35	0.78	0.83	8.3	28	28.47	2.54

*Physical tests were done by the constructional materials laboratory in University of Kerbala and chemical tests were conducted by the Iraqi geological survey.

Table (3-16): Chemical properties for groundwater

$SO_4^{=}$ ppm	4675.5
Cl^- ppm	11182.5
PH	8.45

Table (3-17): Main details of the mixes used throughout this investigation.

Mix Designation	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Mega Flow 110 % by weight of cement	Sika Rapid®1% by weight of cement	SBR % by weight of cement	W/C Ratio	Slump (mm)
Normal	336	760	1044	/	/	/	0.55	85
Polymer	336	760	1044	/	/	7.5	0.475	85
High Strength	420	730	972	1.5	2	/	0.35	85

3.4 Mixing, Placing and Curing Procedures:

According to ASTM ***(ASTM/C31/C31M, 2003)*** mixing, placing and curing of cubies and cylinders specimens and columns have been carried out. After mixing the dry ingredients mix for 5 minutes then added water and additives for polymer and high strength concrete, but only water for normal concrete and mix them, as shown in *Plate (3-4)*. This process has been taken (2-3) minutes to achieve homogenous mix. The process of casting take place at a temperature of 14 c^{o} and completed in 7 days by hand mixing.

All concrete columns, cubes and cylinders were cast in steel molds. The mixes have been casted into cube and cylinder, and column steel molds with sequential layers until its fully filled and vibrated with gasoil engine vibrator. To prevent adhesion of the concrete after hardening the internal surfaces of the steel molds were painted with oil. The specimens were left in the molds for 24 hrs then cured in water until the time of testing, see *Plates (3-5) to (3-11)*.

Plate (3-4): Mixing concrete

Plate (3-5): Molds used to cast column specimens

Plate (3-6): Molds used to cast cubes and cylinders

Plate (3-7): Reinforcement cage of columns

Plate (3-8): Casting and compaction of cubes and cylinders

Plate (3-9): Column specimens left 24 hrs in molds

Plate (3-10): Cubes and cylinder concrete left 24 hrs in molds

Plate (3-11): Extraction specimens from molds

3.5 Experimental Tests:

3.5.1 Testing of Fresh Concrete:

The potential strength and durability of concrete of a given mix proportion are very dependent on the degree of its compaction. It is vital, therefore, that the consistency of the mix be such that the concrete can be transported, placed, and finished sufficiently early enough to attain the expected strength and durability. Thus, consistency of concrete measured by a slump flow test. The slump test is a method used to determine the consistency of concrete. The consistency, or stiffness, indicates how much water has been used in the mix. The stiffness of the concrete mix should be matched to the requirements for the finished product quality. The slump is a measurement of concrete's workability or fluidity.

According to ASTM ***(ASTM/C143C143M, 2005),*** a sample of freshly mixed concrete is placed and compacted by rodding in a mold shaped as the frustum of a cone. The mold is raised, and the concrete allowed to subside. The vertical distance between the original and displaced position of the center of the top surface of the concrete is measured and reported as the slump of the concrete. The slump value was about (85 mm) for all mixes.

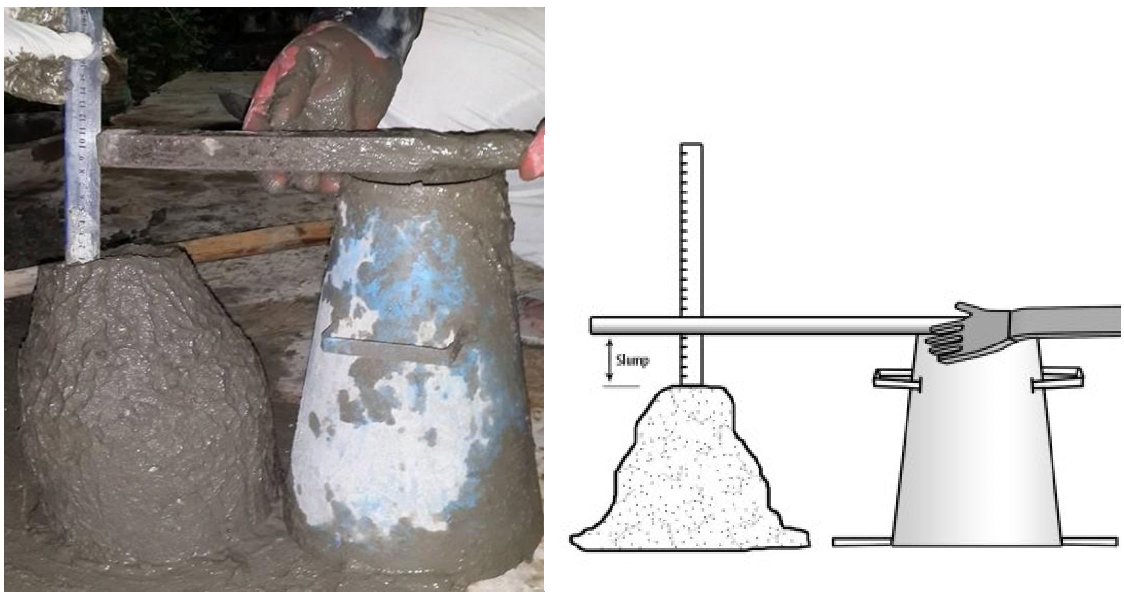

Plate (3-12): Slump flow test

3.5.2 Hardened Concrete Tests:

Various tests on hardened concrete were performed to ensure the design strength of concrete and quality of concrete construction is achieved. Such as compressive strength, splitting tensile strength, absorption, density, and voids tests.

3.5.2.1 Compressive Strength Test:

The compressive strength test has been carried out according to ***(BS1881-116:1983, 2002)***. Total number of (63) cubes of (100×100×100) mm were tested by using a hydraulic compression machine ELE of (2000 kN) capacity, at a loading rate of 3 kN/sec. The average of three cubes had adopted at each test. The specimens have been tested at ages of 28, 60, 150, and 240 days. The specimen was carefully aligned at the center of thrust of the upper bearing block and the loading was applied continuously until failure.

Plate (3-13): Compressive strength test machine

3.5.2.2 Splitting Tensile Strength Test:

The splitting tensile strength has been carried out according to ASTM ***(ASTM/C496-96, 2004)*** specification. Total number of (63) cylinders of (100×200) mm were used. The specimens were tested at ages of 28, 60, 150, and 240 days. Thin plywood was placed on the upper and lower faces of the specimen. The test was performed using a hydraulic compression machine ELE of (2000 kN) capacity, at a rate of 2.4 kN/sec until the failure occurs. The average of three cylinders was taken at each test. The splitting tensile strength is calculated by the following equation:

$$f_{sp} = \frac{2P}{\pi d l} \quad \text{.........................} \quad (3\text{-}1)$$

where:

f_{sp}: Splitting tensile strength, (MPa)

P: Max. applied load indicated by the testing machine, (N)

d: Cylinder diameter, (mm)

l: Cylinder length, (mm)

Plate (3-14): Splitting tensile strength testing

3.5.2.3 Absorption, Density, and Voids Tests:

These tests cover the findings of density, absorption, and voids in hardened concrete according to ASTM ***(ASTM/C642-97, 2004).*** The specimens were tested at ages of 28, 60, 150, and 240 days. A total number of (63) cubes of (100×100×100) mm have been tested by determining the mass of the specimen, and drying in an oven at a temperature of 100 to 110°C for not less than 24 h. Then, after final drying, cooling, and determination of mass immerse the specimen in water at approximately 21°C for not less than 48 h or until two successive values of mass of the surface-dried sample at intervals of 24 hrs show an increase in mass of less than 0.5 % of the larger value. Surface-dry the specimen by removing surface moisture by a piece absorbing water, and determine the mass. Place the specimen in a suitable container, enclosed with tap water, and boil it for 5 hr. Cool it naturally for not less than 14 h to a final temperature of 20 to 25°C. Remove the surface wetness with a dishtowel and determine the mass of the specimen. Suspend the specimen, after involvement and boiling, by a wire and determine the apparent mass in water. By using the values for mass determined by the procedures described, find absorption, density, and voids by the equations below. The average of three specimens was taken at each test.

$$\text{Absorption after immerstion, \%} = \left[\frac{B-A}{A}\right] \times 100 \quad \text{(3-2)}$$

$$\text{Absorption after immerstion and boiling, \%} = \left[\frac{C-A}{A}\right] \times 100 \quad \text{(3-3)}$$

$$\text{Bulk density, dry} = \left[\frac{A}{C-D}\right].\rho = g_1 \quad \text{(3-4)}$$

$$\text{Bulk density after immersion} = \left[\frac{B}{C-D}\right].\rho \quad \text{(3-5)}$$

$$\text{Bulk density after immersion and boiling} = \left[\frac{C}{C-D}\right].\rho \quad \text{(3-6)}$$

Apparent density $= \left[\frac{A}{A-D}\right].\rho = g_2$ .... (3-7)

Volume of permeable pore space voids, % $= (g_2 - g_1)/g_2 \times 100$ .... (3-8)

where:

A = mass of oven-dried sample in air, g

B = mass of surface-dry sample in air after immersion, g

C = mass of surface-dry sample in air after immersion and boiling, g

D = apparent mass of sample in water after immersion and boiling, g

g_1= bulk density, dry, Mg/m^3 and; g_2= apparent density, Mg/m^3

ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

3.6 Reinforced Concrete Columns Models:

All groups of columns, with and without admixtures, were identical in size, 150x150 mm square section with overall height of 1080 mm. The columns were casted in a vertical direction and hardened cured by fresh water conditions until 28-day. After that, they were buried into two different soils with different concentrations of sulfate and chloride solutions for a period of 60, 150, and 240 days as shown in *Plate (3-15)* and *(3-16)*. Then, all groups of columns were tested under axial static load using a mechanical machine with electrical seal load in period 60, 150, and 240 days as shown in *Plate (3-18)*. The capacity of the machine was (1000 kN). The capacity of mechanical dial gauges is (2 cm), while the capacity of electronic dial gauge is (5 cm) for fhe test started with the submission of 7 kN/m^2 load to set and check dial gauge. At zero loading, a preliminary reading of dial gauges is found. The load is applied in stages. At each load addition, notes of crack development on the concrete columns and traced it. Also, at each test, the first cracking load and reading of dial gauges were documented. The process of reading of the gauges and crack remarks took about seven to twelve minutes. Once this progression was completed, the loading was continued to the next load step. The same procedure was followed. The load was continued until reaching the ultimate load capacity. All columns were divided into three groups, (normal, polymer, and high strength R.C.). Each group consisted of 7 columns. The columns have the same amount of longitudinal reinforcement of 4 Ø 8mm and stirrups of 7 Ø 6mm/m. Design R.C. columns were according to ACI code requirements ***(ACI318M-14, 2014)***, $A_{st} = 0.01\ A_g$, $A_g = 150\ \times 150\ \times 0.0085 = 201\ mm^2$; then 4 ∅ 8 mm were used and for ties they were ∅ 6 mm @ 130 mm (7∅ 6 mm/m). Details of reinforcement and measured deformations are shown in Fig. (3-6). The main details of this experimental work for R.C. column models are illustrated in Fig. *(3-7).*

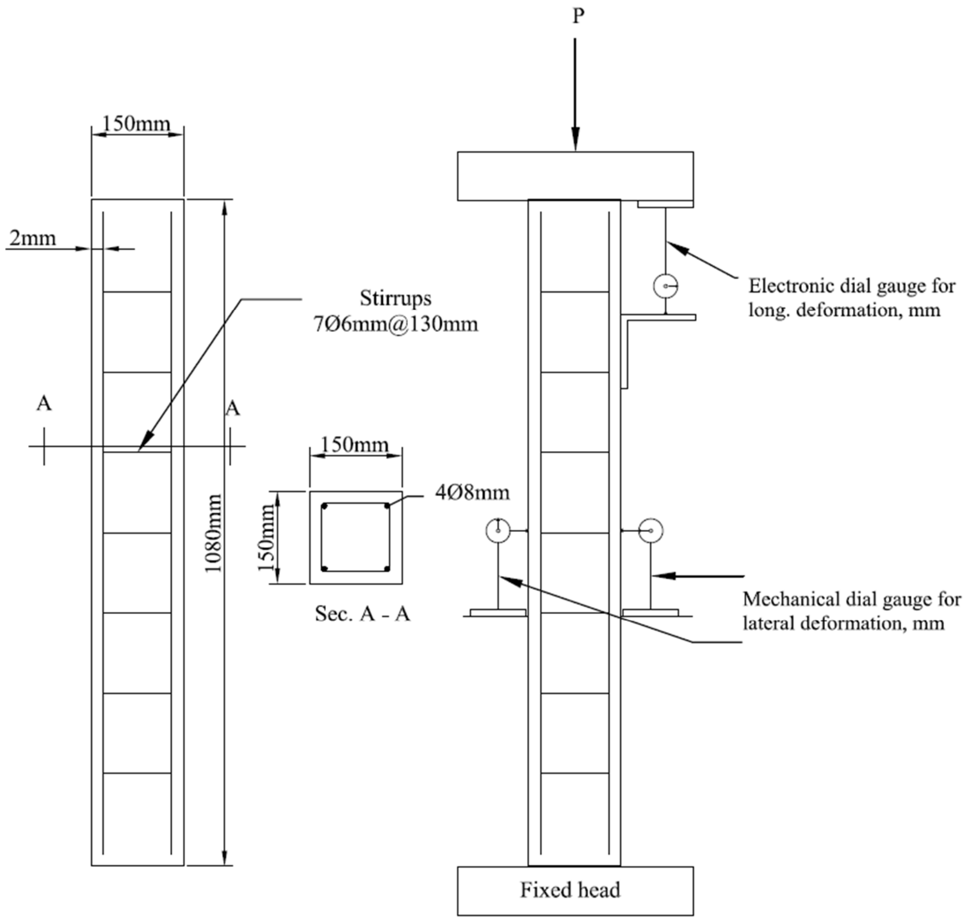

Fig. (3-6): Details of R.C. tested columns and method of measuring their deformations.

Plate (3-15): Preparing specimens for bury

Plate (3-16): Burying the specimens

Plate (3-17): Dial gauge used to measure lateral deflection

Plate (3-18): Testing Mechanical Machine

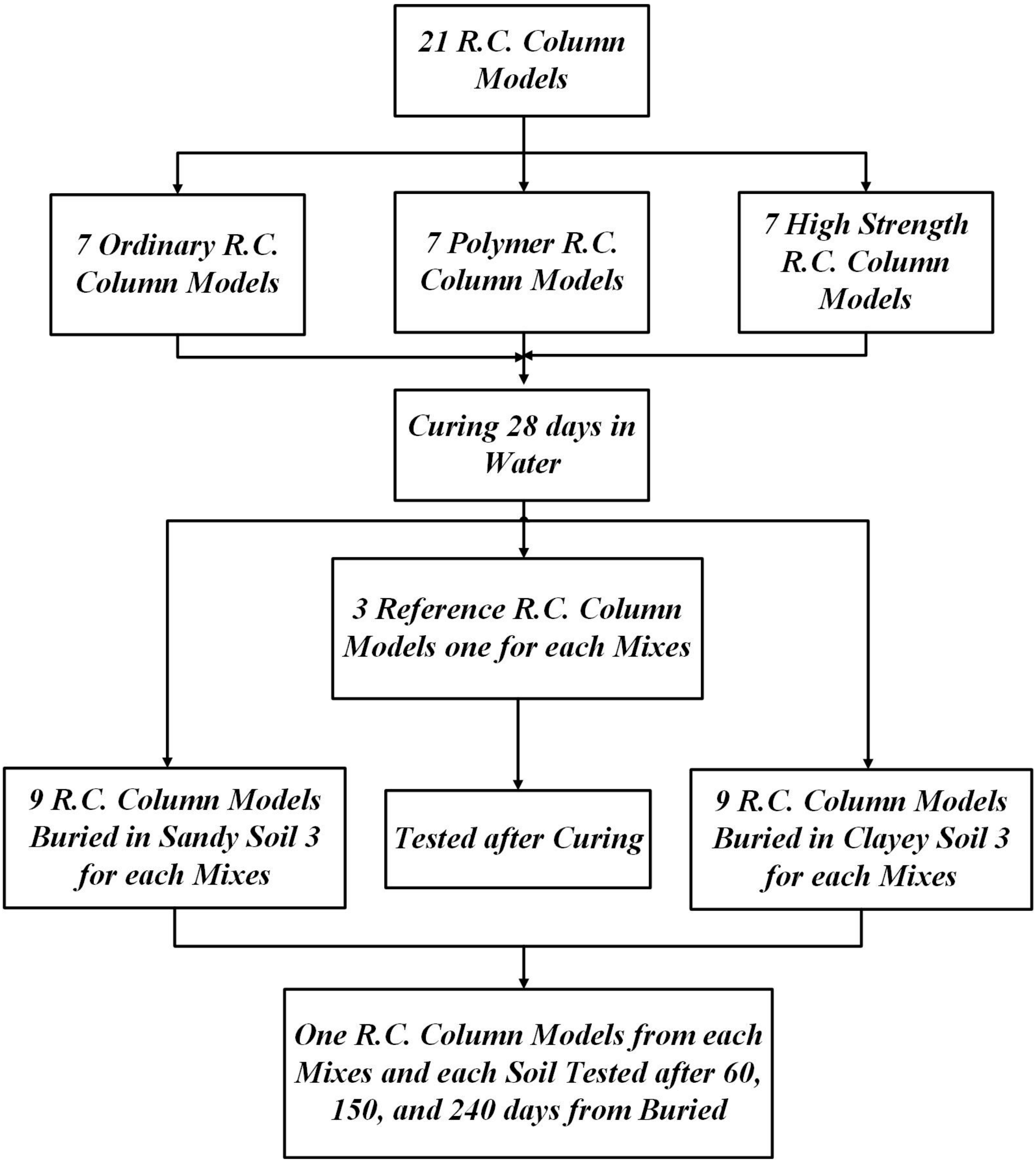

Fig. (3-7): The main details of the experimental work for R.C. column models

Chapter Four

Results & Discussions

CHAPTER FOUR

Results and Discussion

4.1 General:

The main objective of this work is to investigate the structural behavior of reinforced concrete column buried in different types of soils by axial load test. To achieve this objective, an extensive experimental work has been carried out.

Twenty-one reinforced concrete columns were tested under axial compressive load, to study the influence of different variables which are a considered in this work. The experimental variables are mixes, materials, buried time of the specimens, and the soil properties in which the specimens were buried.

Test results are discussed in this chapter based on load-deflection curves up to experimental variables.

4.2 Axial Compression Load for All Reinforced Concrete Columns:

Table (4-2) indicates that the best mix matrix in terms of resistance to sulfates was the high-strength mix. All column specimen's strength decreased with increasing the concentration of sulfate and chloride in clayey and sandy soils. As shown in Figures. *(4-1) through (4-44)*, the highest strength values were recorded for the high-strength mixes, while the lowest strength value was recorded for the polymer mixes. The Poisson's ratio has increased with time in the high strength concrete mix buried in the sandy and clay soils while in other concrete mixes was irregularly.

The load-deformation data obtained from the experimental tests showed that all high-strength reinforced concrete columns had a semi-linear load-deformation relationship, which means that most of the failures are sudden failure. It was also observed that the deformation of high-strength reinforced concrete columns decreases or stay the same with load increasing.

It was noted that the polymer concrete has been affected more than the other concrete mixes by harmful properties of the soils. The results indicate that the strength decrease in the polymer concrete mix is higher than the decreasing occurred in the other mixes, although its ductility was increased with buried time due to the high deformation observed. This behavior might be attributed to the modest properties of polymeric materials in this mix.

Also, it is observed that an increase in the strength of the normal mix, and a decrease in the polymer, mix and high-strength mix. This is due to the crystallization in the normal mix because the presence of salts, which led to the closure of pores and reduce the percentage of voids and absorption in this mix, it is expected over time this crystallization will increase the stresses in concrete, thus increase absorption rate and voids again.

Polymer and high-strength mixes, are basically have a few voids and absorption, so the crystallization works directly on the deposition of the stresses on the concrete and thus increase the percentage of voids and absorption, so decreasing the strength in these mixes, also its noted that the enhancing of strength of normal columns in sandy soil is more than that occurred in clayey soil.

Table (4-1): Percentage of sulfates and chlorides in clayey and sandy soil over time.

Soil Type	***Salt (%)***	***At buried time***	***Time of buried (days)***		
			60	***150***	***240***
Clayey	***Sulfate ($SO4^{=}$)***	2.61	4.41	3.50	3.04
	Chloride (Cl^{-})	0.78	0.78	1.99	0.78
Sandy	***Sulfate ($SO4^{=}$)***	10.6	9.5	9.0	9.6
	Chloride (Cl^{-})	1.95	1.95	1.24	1.07

Table (4-2): Results of the Experimentally Tested Column.

Group Name	Soil Type	Mix Type	Designation Name	Time of Test (day)	Cracking Load (Pcr), (kN)	Failure Load (Pu), (kN)	Long. Def. at ult. load (mm)	Lateral. Def. at ult. load (mm)
Nc	Ref.	Normal	RS1	28	142.92	495	4.8	0.61
	Clayey		N2	60	327.24	490.32	3.45	1.63
			N3	150	440.23	509.76	4.79	0.525
			N4	240	254.16	433.08	3.75	0.98
Pc	Ref.	Polymer	RS2	28	241.2	438.48	4.52	0.47
	Clayey		P2	60	168.48	333.36	7.27	1
			P3	150	140.4	349.56	3	2.93
			P4	240	139.68	329.04	7.43	0.195
Hc	Ref.	High-Strength	RS3	28	267.84	785	6	0.785
	Clayey		H2	60	273.6	773.2	5.8	0.62
			H3	150	197.28	734.04	6.2	1.66
			H4	240	220.32	662.4	4.64	1.4
Ns	Sandy	Normal	NS2	60	158.4	439.2	7.43	1.56
			NS3	150	111.24	529.56	5.23	0.74
			NS4	240	552.96	552.96	3.25	1.28
Ps		Polymer	PS2	60	194.04	302.04	5.25	0.85
			PS3	150	264.96	350.64	6.74	0.9
			PS4	240	104.4	273.96	2.91	0.7
Hs		High-Strength	HS2	60	302.4	785	6.61	1.22
			HS3	150	260.28	637.92	3.96	1.92
			HS4	240	211.32	752.3	4.51	1.12

Table (4-3): Results of the Experimentally Tested Cubes & Cylinders.

Group Name	Soil Type	Mix Type	Time of Test (day)	Comp. Strength (Cube), (MPa)	Tensile Strength (Cylinder), (MPa)	Absorption %	Voids %	Density Mg/m^3
Nc	Ref.	Normal	28	27.75	2.712	5.2061	11.566	2.3457
	Clayey		60	27.365	2.034	3.1967	7.3703	2.383
			150	26.723	3.3502	4.6073	9.7224	2.2076
			240	24.48	3.3815	4.6942	10.665	2.3755
Pc	Ref.	Polymer	28	28.2	2.2356	3.5865	8.177	2.3472
	Clayey		60	27.547	2.2027	3.3016	7.4686	2.3368
			150	26.99	2.6218	4.7271	9.2128	2.0452
			240	30.94	2.921	5.6002	12.236	2.3081
Hc	Ref.	High-Strength	28	46.15	3.5507	2.7942	6.609	2.4292
	Clayey		60	39.167	2.8096	2.2677	5.3909	2.4314
			150	44.85	3.8722	2.8958	6.5885	2.3411
			240	47.06	4.3513	3.1885	7.45	2.4093
Ns	Sandy	Normal	60	27.767	2.0865	3.3125	7.5891	2.3665
			150	27.013	2.7194	4.3789	9.3165	2.2212
			240	29.75	3.9142	4.9412	11.037	2.3435
Ps		Polymer	60	21.353	1.7242	3.7177	8.3208	2.3214
			150	28.09	3.008	4.4502	9.3237	2.1895
			240	22.83	3.1911	6.9013	14.754	2.2891
Hs		High-Strength	60	38.863	3.8717	2.126	5.0712	2.4393
			150	32.453	3.5683	3.5785	7.6888	2.2279
			240	31.87	4.294	3.9208	9.1248	2.4192

4.3 Results of Hardened Concrete Properties:

From each mix, 42 cubes and 21 cylinders were cast and buried in soils with columns and tested to find the mechanical properties of the concrete mixes. As shown in Table (4-3), several laboratory testing methods were performed, including: compressive strength, splitting tensile strength, absorption, voids and density. The results listed in Table (4-3) were the average of three specimens for each of these mechanical properties.

The compressive strength increase with time in polymer and high-strength mixes buried in the clayey soil, however the strength of those mixes decreased in the sandy soil. The strength of normal mix decreased in clayey soil with time and increased in sandy soil, as described in *Table (4-4)*.

The results indicated that the tensile strength of concrete cylinders increased over time for all concrete mixes. This behavior may impute to the salts which work to improve ties between the concrete particles. The tensile strength improvement is temporary, and it is expected at developed ages the strength will return to decline.

The absorption has increased with time in polymer and high-strength mixes and the largest increase was in the mix polymeric. The maximum increment in the absorption was recorded for cubes buried in the sandy soil for (240 days) by 92.42% and in cubes buried in the clayey soil by 56.15% for (240 days) compared with the reference cubes, while it was (40.32, 14.11) % for high-strength buried in sandy and clayey soils respectively, for the same tested time, but the absorption decreasing by (5.09, 9.83) % for normal mix buried in sandy and clayey soil respectively, for the same tested time.

It was also noted that the percentage of voids in concrete cubes increased with time in polymer and high-strength concrete mixes, however the largest increase was in the polymer mix. After 240 days, the polymer concrete exhibits a voids ratio increases of 80.43%in sandy soil and 49.64% increase in the clayey soil. For high strength concrete mixes, the voids ratio increased by 38.07 and 12.73% for the concrete specimens 240-day buried in the sandy and clayey soils, respectively. For normal concrete mixes, the void ratio decreased by 4.57 and 7.79% for the cubes buried in sandy and clayey soils after 240 days.

From the above, and *Table (4-4)*, the percentage of voids and the absorption ratio in the normal mix were decreased, and in the polymer and high-strength mixes were increased.

Table (4-4): Summery for the percentage change of hardened concrete properties

Group Name	Soil Type	Time of Test (day)	Comp. Streng. %	Tensile Streng. %	Absorp. %	Voids %	Density %
Nc	Clayey	60	-1.39	-25.00	-38.60	-36.28	1.59
		150	-3.70	23.53	-11.50	-15.94	-5.89
		240	-11.78	24.69	-9.83	-7.79	1.27
Pc		60	-2.32	-1.47	-7.94	-8.66	-0.44
		150	-4.29	17.28	31.80	12.67	-12.87
		240	9.72	30.66	56.15	49.64	-1.67
Hc		60	-15.13	-20.87	-18.84	-18.43	0.09
		150	-2.82	9.05	3.64	-0.31	-3.63
		240	1.97	22.55	14.11	12.73	-0.82
Ns	Sandy	60	0.06	-23.06	-36.37	-34.38	0.89
		150	-2.66	0.27	-15.89	-19.45	-5.31
		240	7.21	44.33	-5.09	-4.57	-0.09
Ps		60	-24.28	-22.88	3.66	1.76	-1.10
		150	-0.39	34.55	24.08	14.02	-6.72
		240	-19.04	42.74	92.42	80.43	-2.48
Hs		60	-15.79	9.04	-23.91	-23.27	0.42
		150	-29.68	0.50	28.07	16.34	-8.29
		240	-30.94	20.93	40.32	38.07	-0.41

4.4 Effect of Aggressive Solution of Clayey Soil on Buried Reinforced Concrete Columns:

To understand the effect of sulfate and chloride on different reinforced concrete columns, three mixes were used in the current work, and buried for 60, 150, and 240 days in clayey soil to investigate their behavior.

4.4.1 Normal Reinforced Concrete Columns:

First cracks were observed in the normal reinforced concrete columns group (Nc) at top and bottom of these columns at applied load of (142.92, 327.32, 440.32 and 254.16) kN for columns (RS1, N2, N3 and N4) respectively, see *Plate (4-1)*. The cracks propagate and grow, through the load progressing. At the final stages of loading the columns reached ultimate loads at (495, 490.32, 509.76 and 433.08) kN for columns (RS1, N2, N3 and N4) respectively, the failure Pattern of the group (Nc) shows in *Plates (4-2) to (4-5)* all marked loads must be adjusted by factor (3.6).

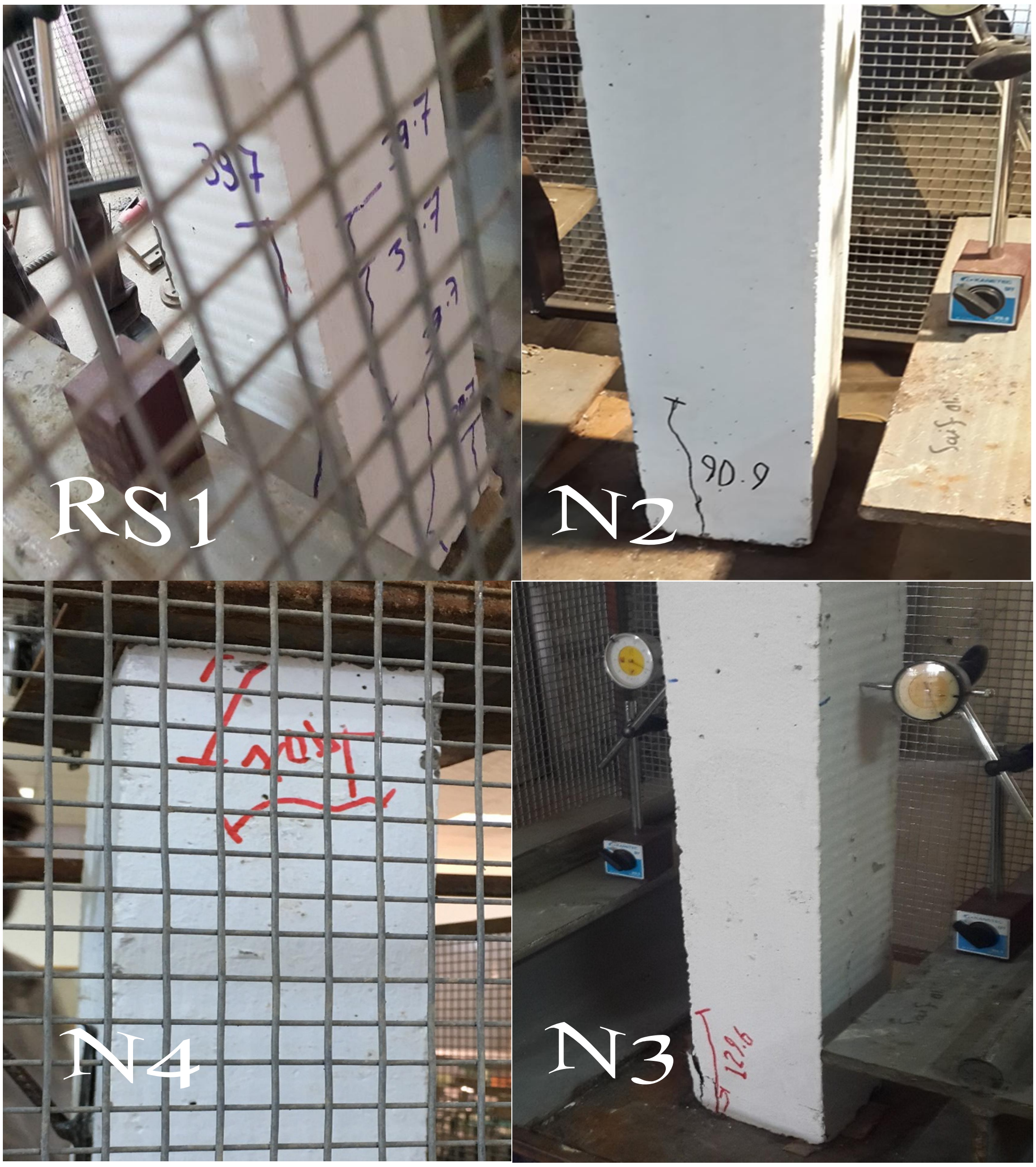

Plate (4-1): First cracks for group (Nc)

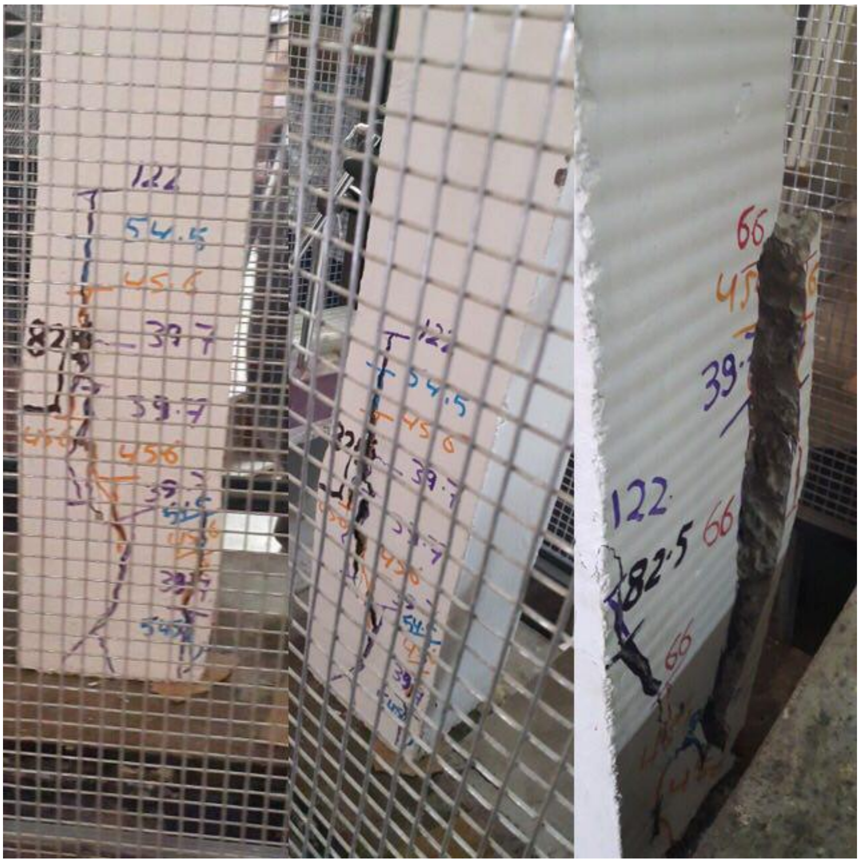

Plate (4-2): Failure Pattern for column (RS1)

Plate (4-3): Failure Pattern for column (N2)

Plate (4-4): Failure Pattern for column (N3)

Plate (4-5): Failure Pattern for column (N4)

The failure occurred gradually with increasing loads at the developed ages, while the longitudinal deflection decrease resulting in a decrease in an overall area under the load – deformation curve. Therefore, the toughness and ductility of the columns constrict with time due to the low load-deflection response (i.e., small area under the curve). *Fig. (4-1)* shows that the deflection was decreased with in increasing buried time for the columns tested under the same loading, which means decreasing the ductility and toughness.

As seen in the *Fig. (4-2),* the lateral deflection increases over time at the same load as example (400 kN). From *Table (4-2)*, it can be seen that, the ultimate load lightly enhanced until 150 days of buried, while the harm effected of sulfate and chloride was seen after this time, the cracking load, and failure load of N2, N3 and N4 with respect to RS1 are (229, 308 and 171) %, and (99, 103 and 87) %, respectively.

A possible reason for this increment in the lateral and longitudinal deflection is that, the effect of the sulfate and chloride in clayey soil on the strength of columns during the time of buried.

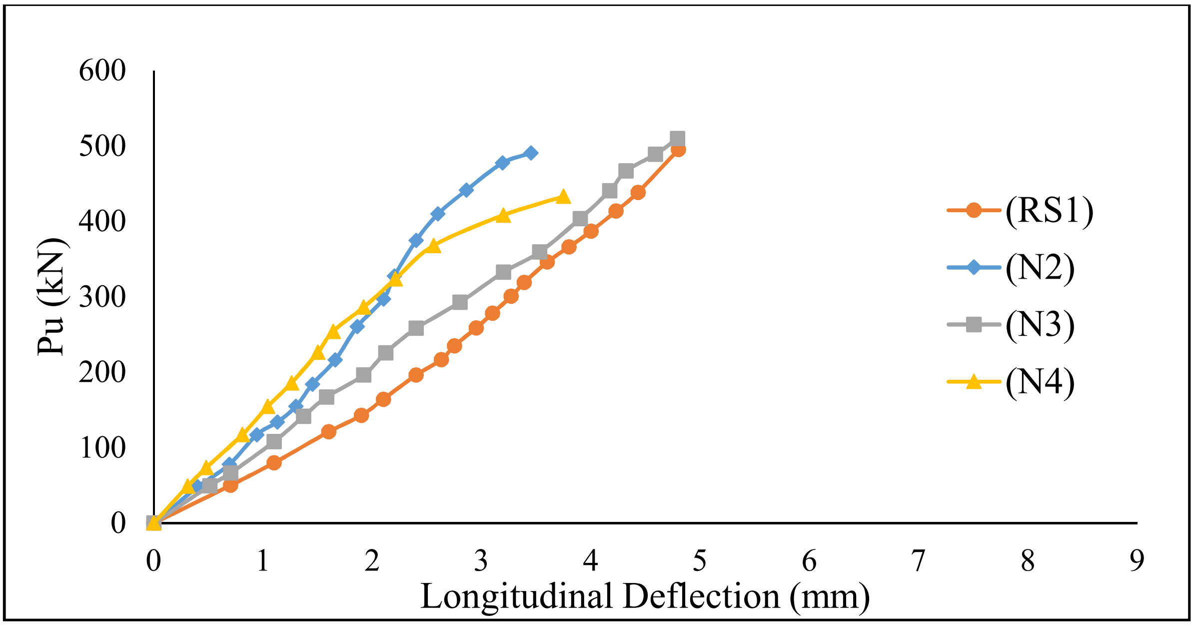

Fig. (4-1): Load – Longitudinal Deflection Behavior of ***Normal*** *R.C. Columns Buried in Clayey Soil*

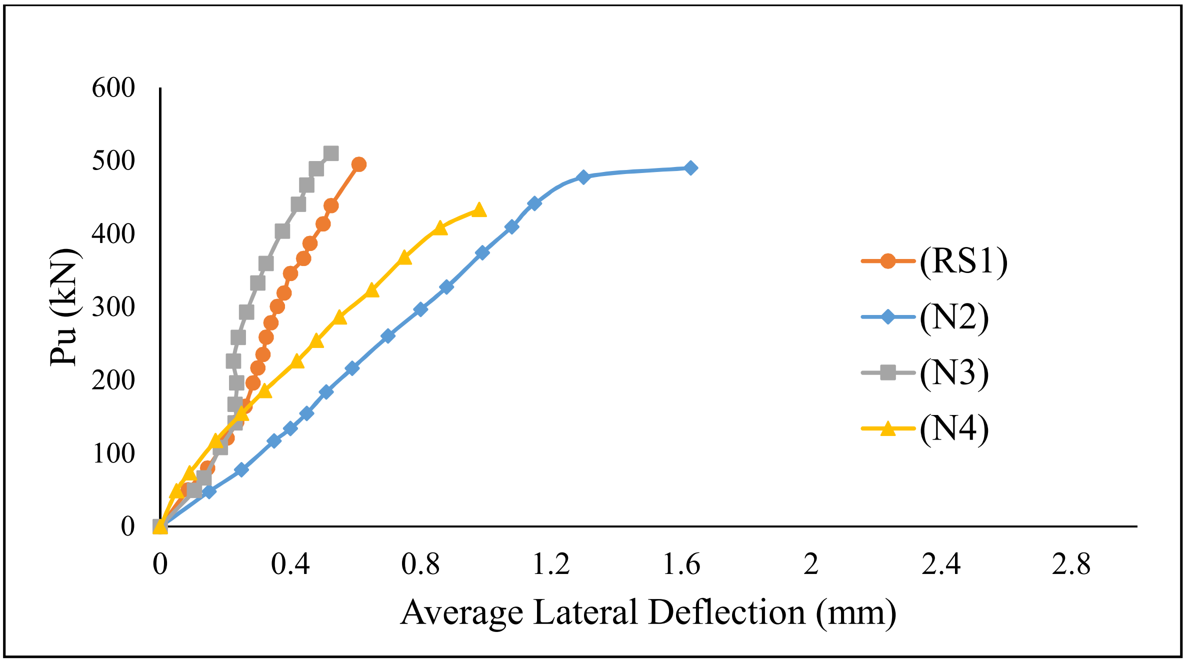

*Fig. (4-2): Load – Lateral Deflection Behavior of **Normal** R.C. Columns Buried in Clayey Soil*

4.4.2 Polymer Reinforced Concrete Columns:

First cracks of the polymer reinforced concrete columns group (Pc) were seen at top and bottom of these columns at the applied loads (241.2, 168.48, 140.4 and 139.68) kN for columns (RS2, P2, P3 and P4) respectively. The strength of this mix became less during buried in the soils. *Plate (4-6) shows locations of the cracks developed in tested columns.* The cracks increased growing and become wider with loads. The columns reached the ultimate loads at (438.48, 333.36, 349.56, & 329.04) kN for columns (RS2, P2, P3 and P4) respectively. The failure Pattern of group (Pc) is shown in *Plates (4-7) to (4-10).*

Plate (4-6): First cracks for group (Pc)

Plate (4-7): Failure Pattern for column (RS2)

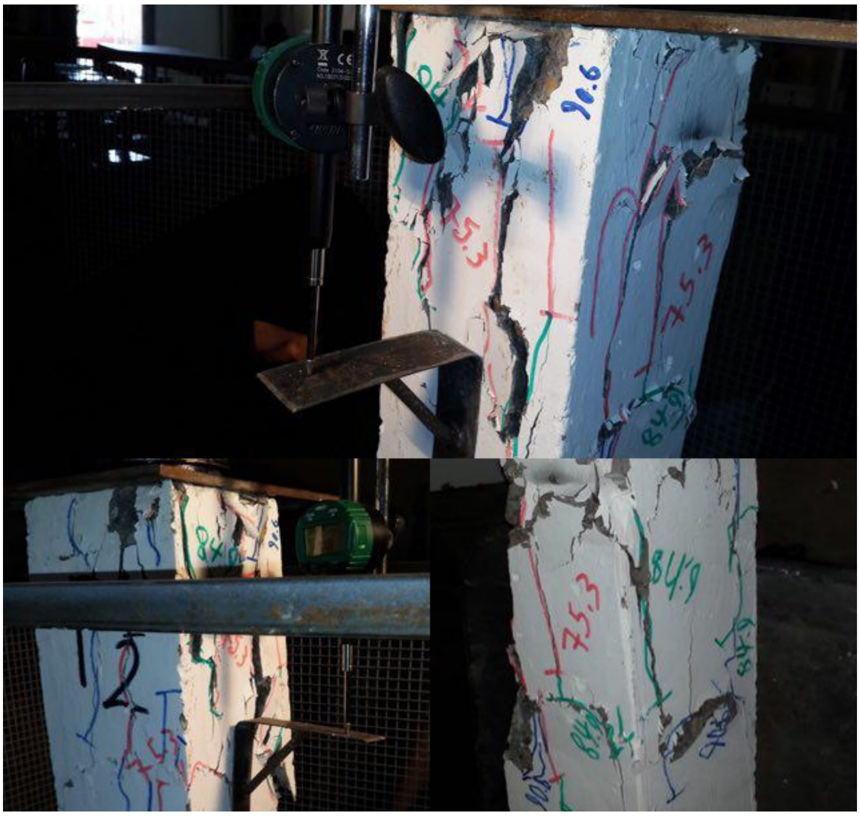

Plate (4-8): Failure Pattern for column (P2)

Plate (4-9): Failure Pattern for column (P3)

Plate (4-10): Failure Pattern for column (P4)

The failure occurred gradually in this group and with increasing the loads at developed ages deflection increase in longitudinal directions, thus increase the area under the curve of load – deformation. This trend would make the columns to become more ductile with time. It was also found that the increase in the longitudinal deflections, decrease the toughness of the columns, except the column (P3) at test time (150 days), which has behavior like column (RS2), see *Fig. (4-3)*.

Under the same loading conditions, the lateral deflections decrease over the time, see Figure (4-4), except the column (P3) which exhibits different behavior.

From *Table (4-2)*, it can be seen that, cracking load, and failure load of P2, P3 and P4 compared to RS2 are (69, 58 and 58%), and (76, 79 and 75%) respectively.

The reason behind these phenomena may be due to the effect of sulfate on the polymer mix because of large voids in the mix led to the entry of sulfate into the concrete but with time interactions in polymeric materials occurred led to the production of molecules which strengthen the concrete, and raising the resistance again. Also, the percentage of sulfates has declined in the clayey soil at150 and 240 days because of the low groundwater table. The drop-in groundwater level minimizes salts concentration in the soil and improves concrete strength due to the lack of exposure to the sulfate attack.

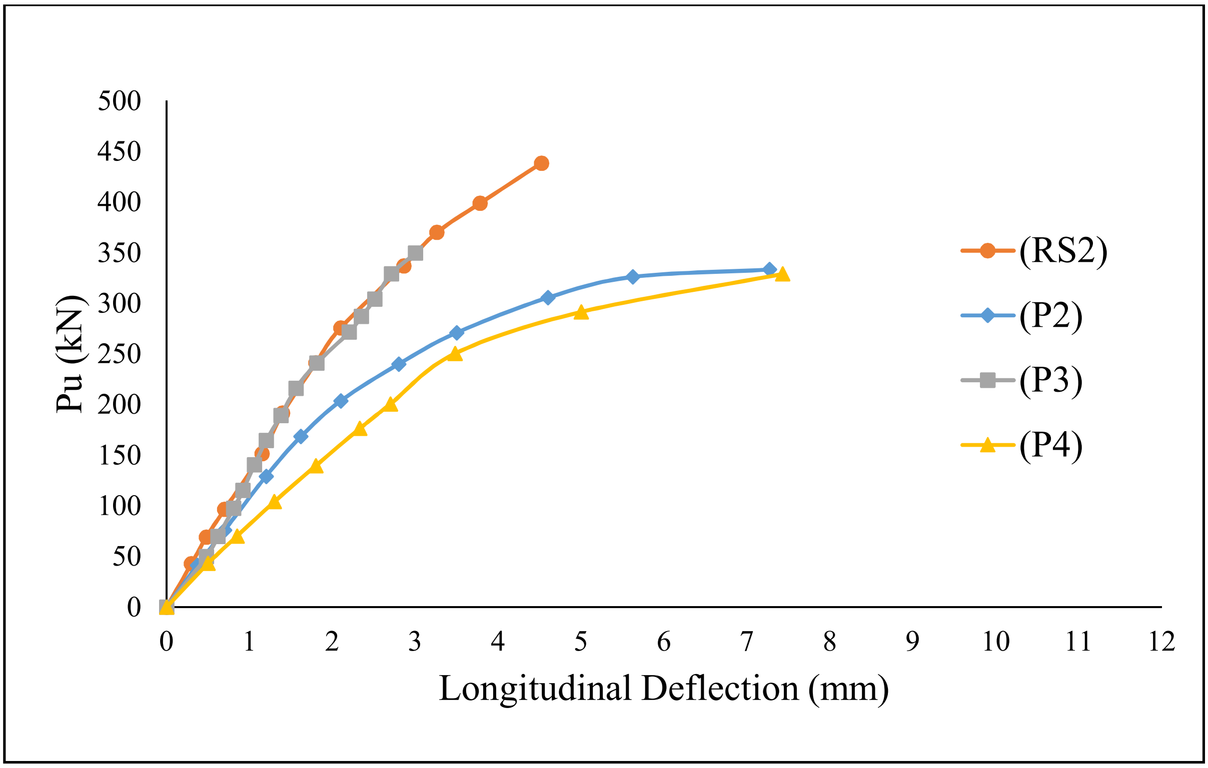

Fig. (4-3): Load – Longitudinal Deflection Behavior of ***Polymer*** *R.C. Columns Buried in Clayey Soil*

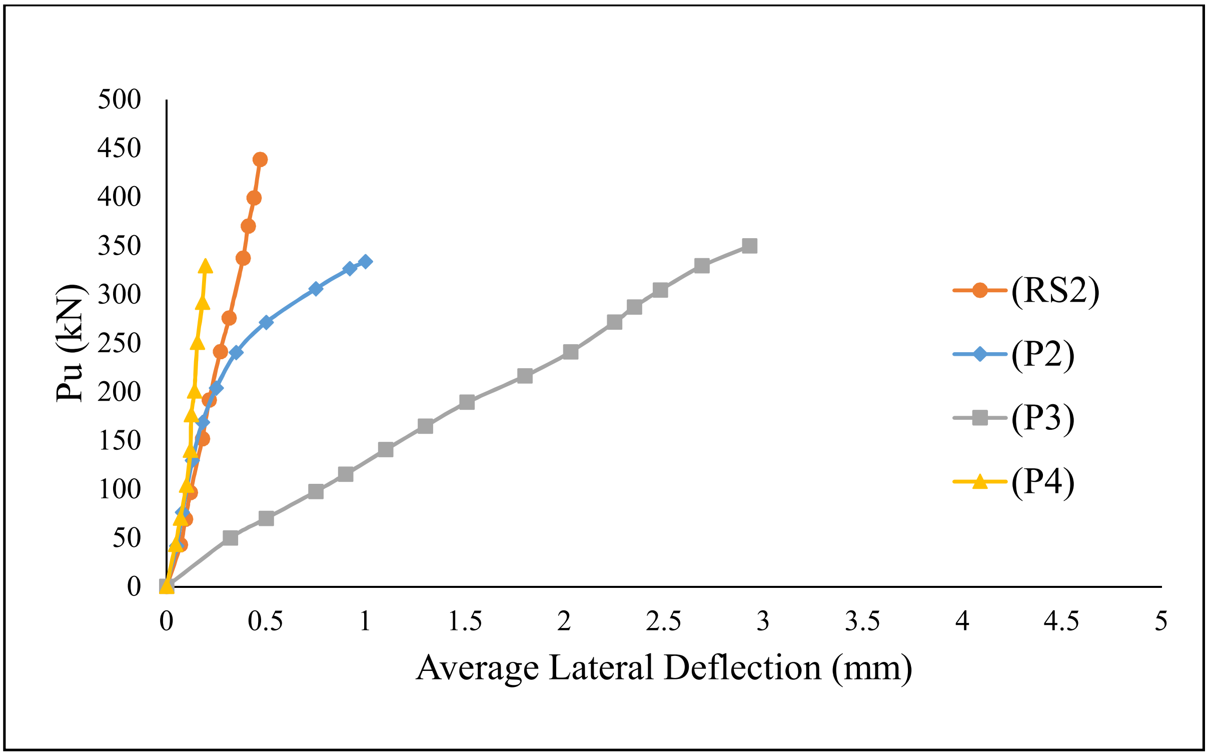

Fig. (4-4): Load – Lateral Deflection Behavior of ***Polymer*** *R.C. Columns Buried in Clayey Soil*

4.4.3 High-Strength Reinforced Concrete Columns:

Initial cracks of the high-strength reinforced concrete column group (Hc) were marked in top and bottom of these columns at the applied loads of (267.84, 273.6, 197.28 and 220.32) kN for the columns (RS3, H2, H3 and H4), respectively. The location and length of these cracks are illustrated in *Plate (4-11)*. The cracks are growing with load increment. The group approached the ultimate loads were (785, 773.2, 743.04, & 662.4) kN for the columns (RS1, H2, H3, & H4) respectively. The columns at failure loads are displayed in *Plates (4-12) through (4-15)*.

The phenomena of failure for this mix is almost sudden due to the high compressive strength. Although the tested columns possess a high strength, they become less ductile and tough with time. The longitudinal deflections decrease at developed ages due to the decrease in the columns toughness and ductility, see Figure (4-5).

As shown in the *Fig. (4-6)* the lateral deflection increases over time at the same load as example (450 kN), lead to increase the Poisson's ratio of tested columns. From *Table (4-2)*, it can be seen that, cracking load, and failure load of H2, H3 and H4 compared to RS3 are (102, 73 and 82%), and (98, 93 and 84%), respectively.

As shown in Fig. (4-5) and *(4-6), it* can be concluded that the best concrete tested is the high-strength concrete. It is less effected, when exposed to sulfate inside the clay soil with time. This behavior is reflected on the sustainability over time and slightly effected by harmful solvents in the soil.

Plate (4-11): First cracks for group (Hc)

Plate (4-12): Failure Pattern for column (RS3)

Plate (4-13): Failure Pattern for column (H2)

Plate (4-14): Failure Pattern for column (H3)

Plate (4-15): Failure Pattern for column (H4)

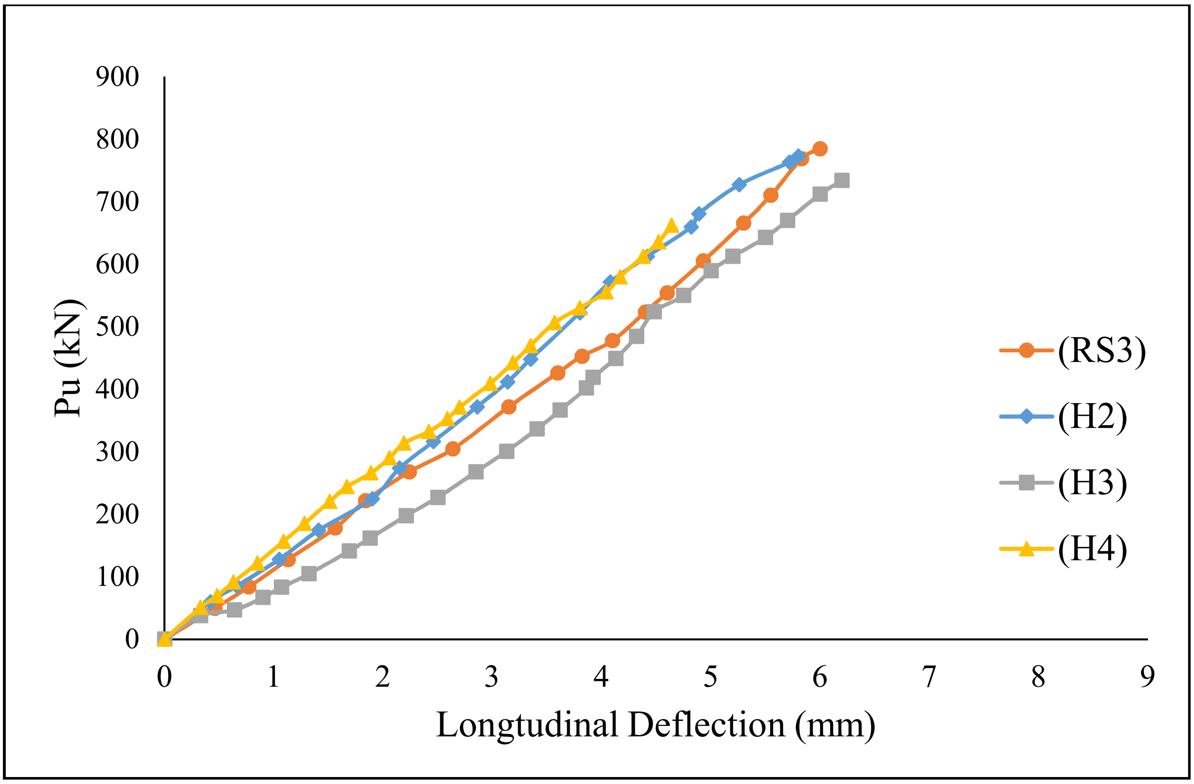

Fig. (4-5): Load – Longitudinal Deflection Behavior of ***High-Strength*** *R.C. Columns Buried in Clayey Soil*

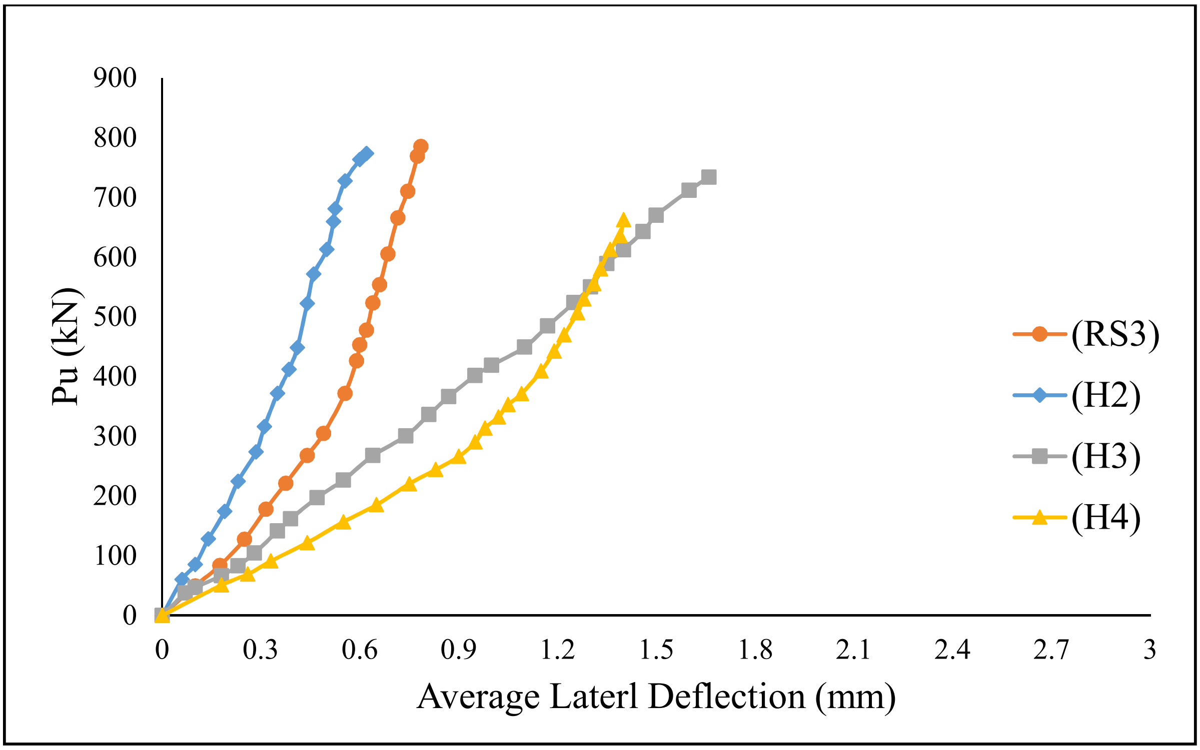

Fig. (4-6): Load – Lateral Deflection Behavior of ***High-Strength*** *R.C. Columns Buried in Clayey Soil*

4.5 Time Effect of Reinforced Concrete Columns Buried in Clayey Soil:

The behavior of the reference concrete columns of the three concrete mixes showed that the high-strength reference mix was the most ductile among the reference mixes, while the normal reference mix was the most brittle concrete, see Figure (4-7)

After 60 days columns in the clayey soil showed clear differences in the behavior of mixes, where the ductility of the polymer concrete mix was very clear with a significant reduction in strength by 23.97%, but the high - strength and normal mixes have remained conservative on their behavior and were little effected by sulfate salts with a decreasing of (0.95, 1.5) % for normal and high-strength mixes respectively. Visually there is no penetration of sulfate inside columns for all columns in this age, conclusion covered in the *Fig. (4-8).*

At the age of 150 days, the columns buried in the clayey soil showed an increase in the strength of the polymer-concrete columns and the normal-concrete columns, however the ductility of those columns were decreased compared to the reference mixes. This behavior may be due to the low proportion of sulfates in the soils at this age, as shown in *Table (4-1)* and *Fig. (4-9)*. The percent of decreasing of polymer mix strength was 20.28% with respect to reference column (RS2), the present of decreasing of high-strength mix strength was 6.49% with respect to reference column (RS3), while there was enhancing in the normal mix strength by 2.98% with respect to reference column (RS1). Based on a visual inspection, there was a penetration of sulfates in the polymer, normal and high-strength columns for a depth of 5, 3 and 1.5 cm, respectively at (150) days age.

At the age of 240 days of burial in the clayey soil, the concrete in the three mixes returned to its former behavior again with decreasing in strength due to the high percentage of sulfates in the soil, as illustrated in *Table (4-1)* and *Fig. (4-10)*. The decreasing percentage of the strength in normal, polymer and, high-strength columns were 12.51%, 24.96% and, 15.62% respectively with respect to reference columns. There is a penetration of sulfates in the polymer mix for depth (7 cm) and (3.5 cm depth) in normal mix, while a (2 cm) in high-strength mix from visual vision.

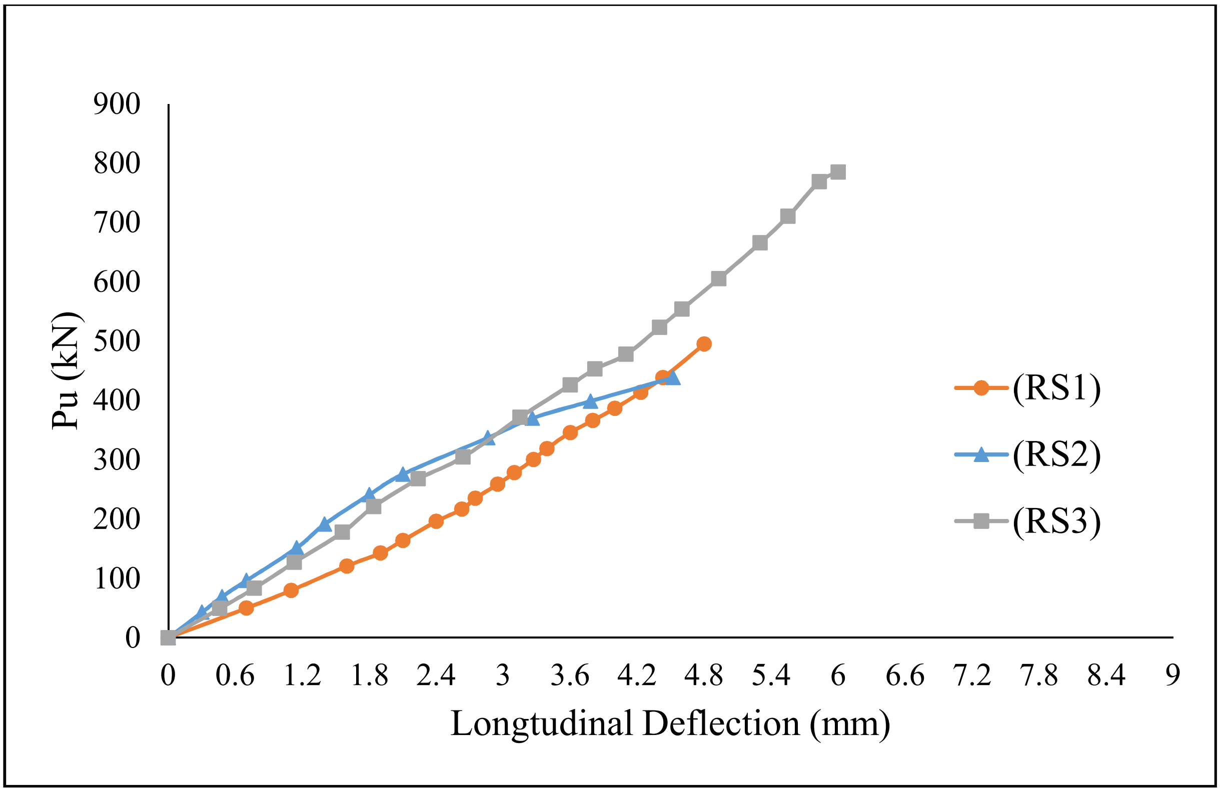

*Fig. (4-7): Load – Longitudinal Deflection Behavior of **Reference** R.C. Columns*

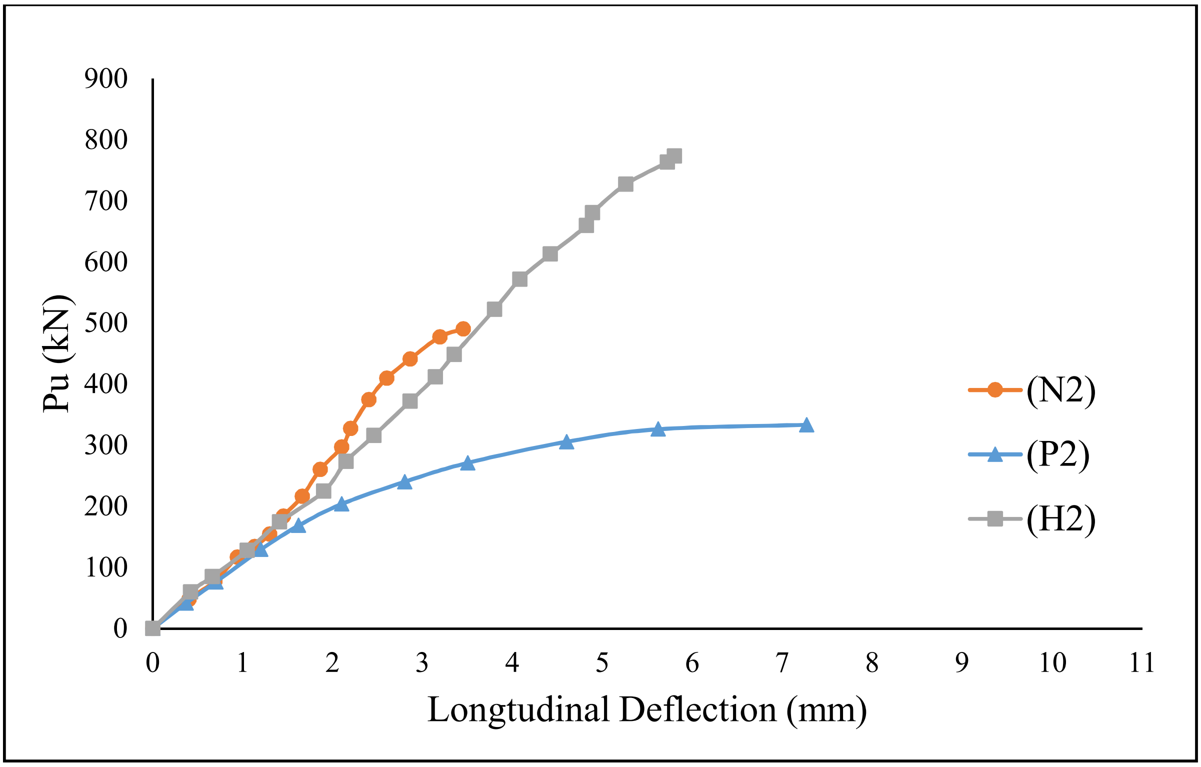

Fig. (4-8): Load – Longitudinal Deflection Behavior of ***Normal*****,** ***Polymer*** *and* ***High-Strength*** *R.C. Columns Buried in Clayey Soil for* ***60 days***

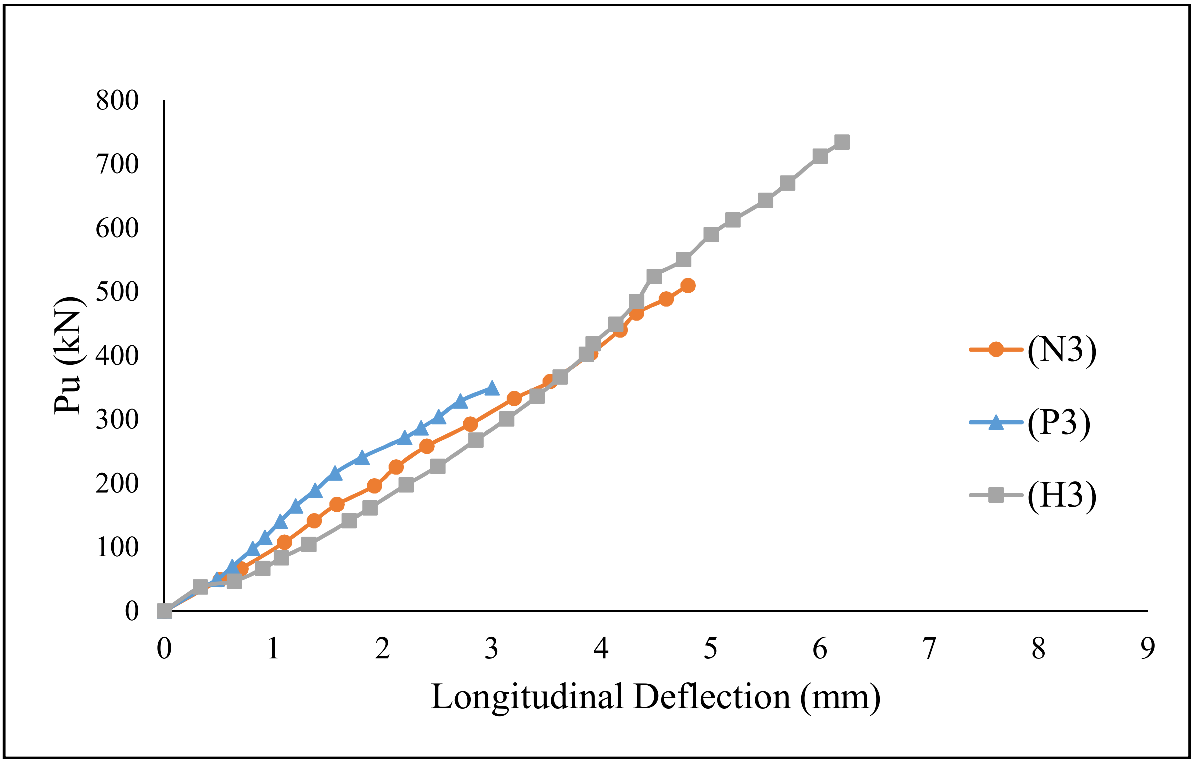

Fig. (4-9): Load – Longitudinal Deflection Behavior of ***Normal*****,** ***Polymer*** *and* ***High-Strength*** *R.C. Columns Buried in Clayey Soil for* ***150 days***

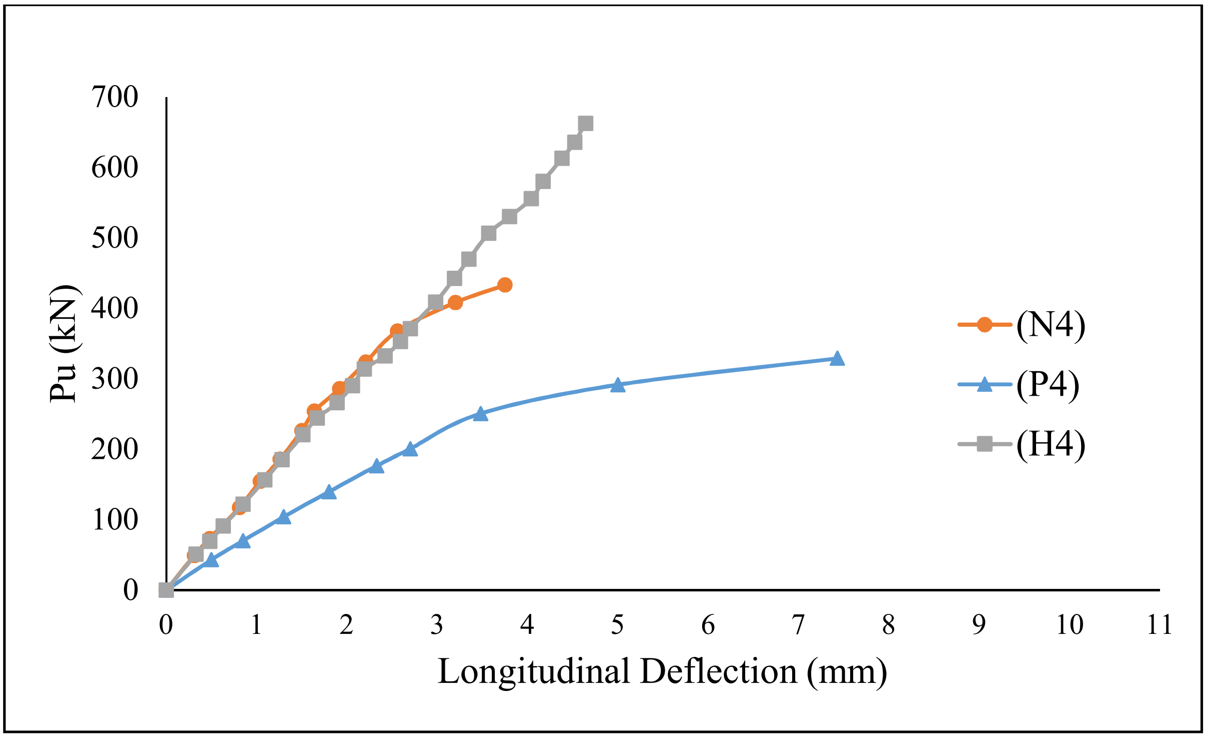

Fig. (4-10): Load – Longitudinal Deflection Behavior of ***Normal, Polymer*** *and* ***High-Strength*** *R.C. Column Buried in Clayey Soil for* ***240 days***

4.6 Effect of Aggressive Solution in Sandy Soil on Buried Reinforced Concrete Columns:

Three mixes were buried for 60 ,150, and 240 days in the sandy soil to understand the effect of sulfate attack on different reinforced concrete columns.

4.6.1 Normal Reinforced Concrete Columns:

The initial cracks in the normal reinforced concrete columns group (Ns) were recorded at top and bottom of these columns at applied load of (142.92, 158.4, 111.24 and 552.96) kN for columns (RS1, NS2, NS3 and NS4) respectively, NS4 fail suddenly without identifying the location of initial cracks. *Plate (4-16)* displays the locations of the cracks. With increasing applied testing load, the cracks increase growing and become wider. The columns reached ultimate loads at (495, 439.2, 529.56 and 552.96) kN for columns (RS1, NS2, NS3 and NS4) respectively, failure Pattern of group (Ns) is shown in *Plates (4-17) to (4-19)*.

Plate (4-16): First cracks for group (Ns)

Plate (4-17): Failure Pattern for Column (NS2)

Plate (4-18): Failure Pattern for Column (NS3)

Plate (4-19): Failure Pattern for Column (NS4)

Columns failure was occurred gradually, except column (NS4) which fails suddenly. Its observed for 60 days age of the column the compressive strength was decreased then its increased in the developed ages to reached its large strength at 240 days age. This means there was improvement in strength with 6.98% and 11.71% at 150 and 240 days ages, respectively compared to the reference strength. This behavior happened due to the decrease of the sulfate concentration in the sandy soil at 150 and 240 days, see *Table (4-1)*.

The results also indicated that longitudinal deflections decreased with time, resulting in an increase in strength and stiffness characteristics of the columns. However, the toughness and ductility of the columns decreases with time.

As seen in the *Fig. (4-12)* the lateral deflection increases over time at the same load, these increments were the reflection the decrements in the longitudinal direction.

From *Table (4-2),* it can be seen that, cracking load, and failure load of NS2, NS3 and NS4 with respect to RS1 are (118, 77and 386) %, and (88, 106 and 111) %, respectively. The effect of the sulfate in the sandy soil on the strength of columns during the time of buried is a possible reason for this increment in the lateral and longitudinal deflection.

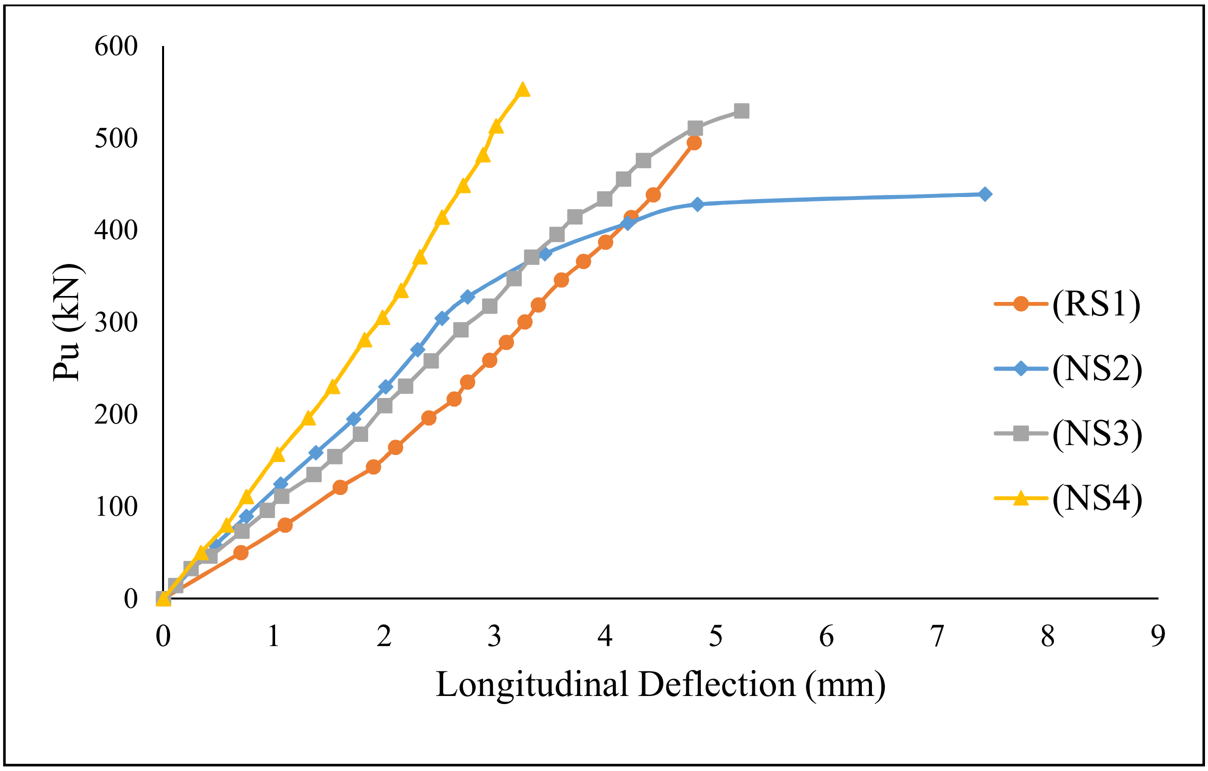

Fig. (4-11): Load – Longitudinal Deflection Behavior of ***Normal*** *R.C. Columns Buried in Sandy Soil*

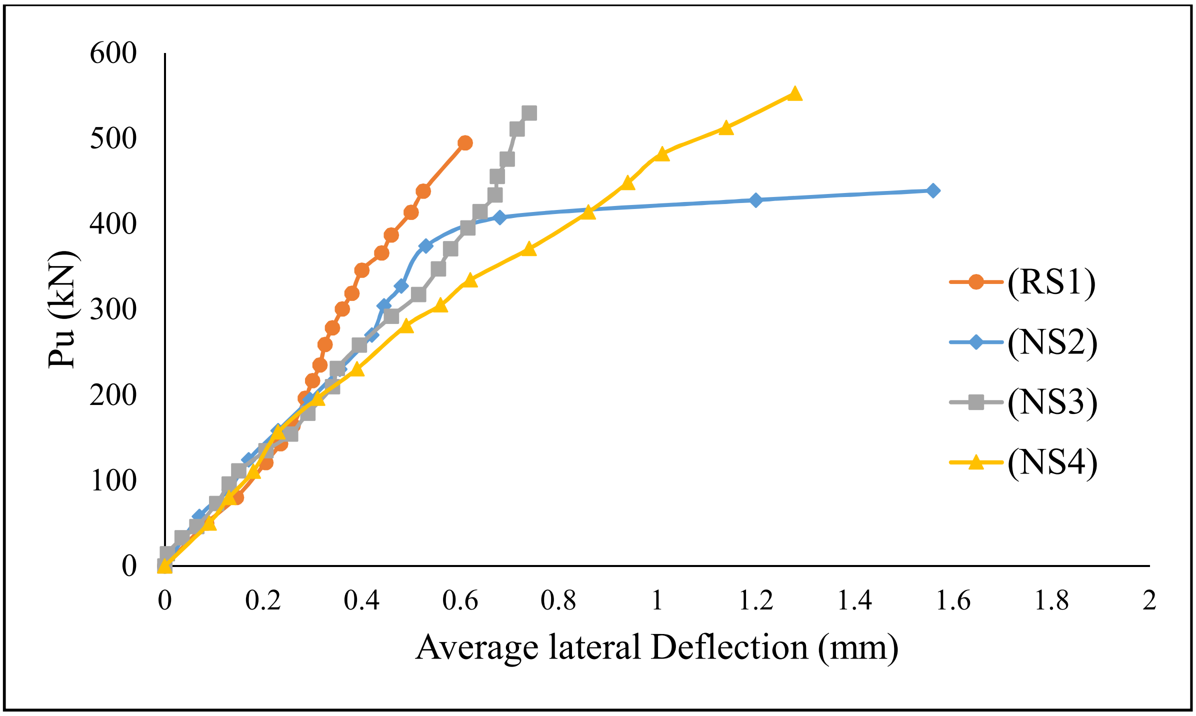

Fig. (4-12): Load – Lateral Deflection Behavior of ***Normal*** *R.C. Columns Buried in Sandy Soil*

4.6.2 Polymer Reinforced Concrete Columns:

First cracks of the polymer reinforced concrete columns group (Ps) were observed at top and bottom of these columns at the applied loads (241.2, 194.04, 264.96 and 104.4) kN for the columns (RS2, PS2, PS3 and PS4), respectively. The strength of polymer concrete drops during the buried time in the soil. The cracks locations are illustrated in *Plate (4-20).*

With loads increasing the cracks became clear, grew and become broader. The columns reached the ultimate loads at (438.48, 302.04, 350.64 and 273.96) kN for columns (RS2, PS2, PS3 and PS4) respectively, failure Pattern of group (Ps) show in *Plates (4-21) to (4-23).*

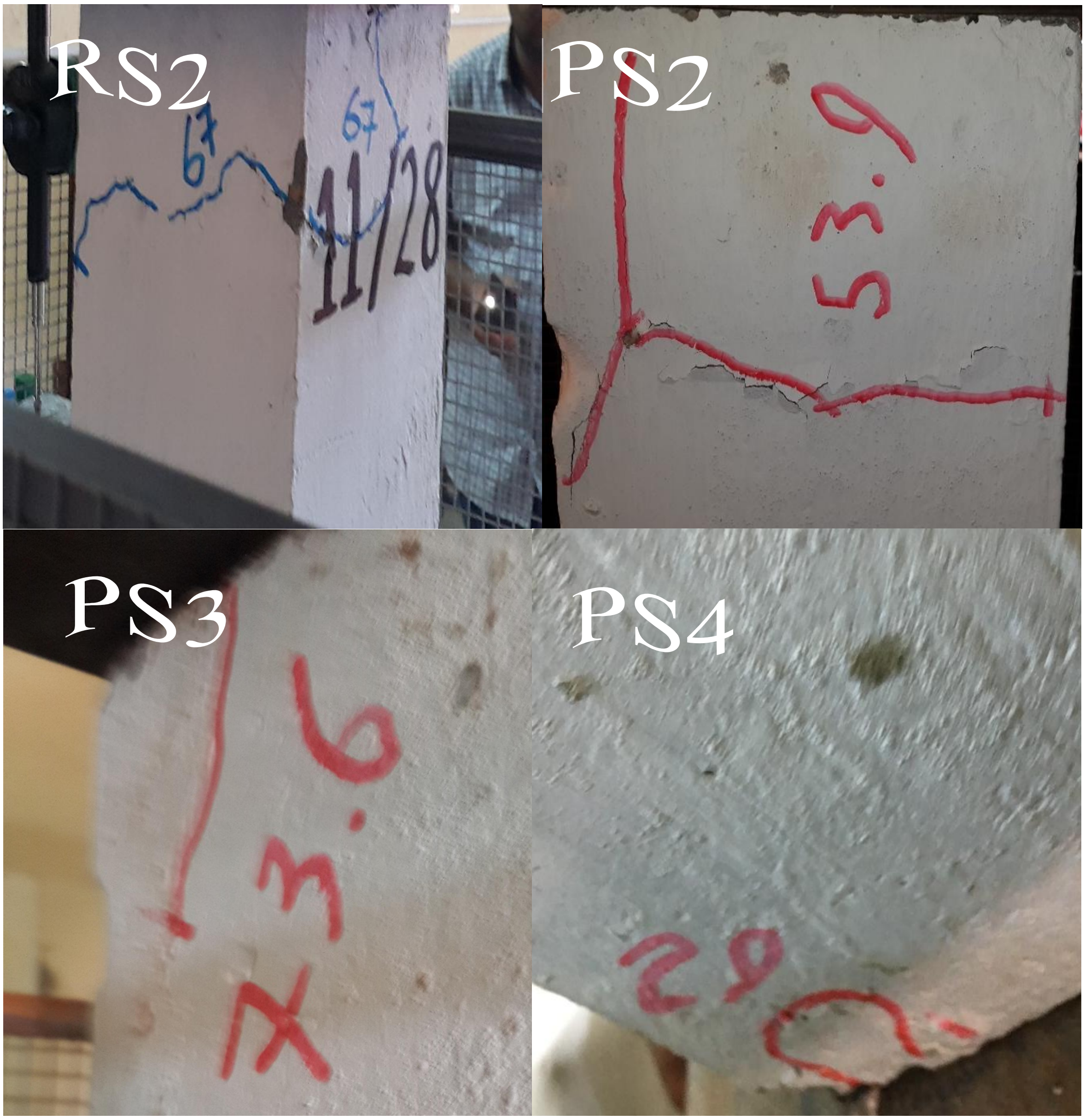

Plate (4-20): First cracks for group (Ps)

Plate (4-21): Failure Pattern for column (PS2)

Plate (4-22): Failure Pattern for column (PS3)

Plate (4-23): Failure Pattern for Column (PS4)

A gradual failure was recorded for this group (Ps) while at developed ages the longitudinal deflection was decreased with loading decrease so the area under the curve of load- deformation also decreased, resulting in a decrease in toughness and ductility of the columns, see *Fig. (4-13)*.

It was observed that the polymer mix is more effected by aggressive salts in the sandy soil than the other mixes. the decrease in strength of the polymer mix was about 37.52% at 240 days age. Additionally, the ductility of polymer concrete was less than other mixes due to high deformations in the load-deformation curves. It was also observed an increase in the strength of the reinforced concrete columns during mid-age test of 150 days, compared with previous values, after that, the strength decreased with time. *Fig. (4-14)* shows the lateral deflections over time at the same load.

From *Table (4-2),* it can be seen that, the cracking load, and the failure load of PS2, PS3 and PS4 to RS2 are (80, 109, and 43%) and (68, 80, and 62%), respectively.

The reason behind this that the polymer mix is significantly affected by the sulfate because of large voids in the mix led to the entry of sulfate into the concrete but, with time interactions in polymeric materials occurred led to the production of molecules has worked to strengthen the concrete, and raising the resistance again. Also, the percentage of sulfates has declined at the sandy soil at age (150 days), after that and the percentage increased at (240 days) of the test, because of the low water table, reducing the concentration of salts in it, this making concrete improves its strength due to lack of exposure to the sulfate at (150 days) test age, and otherwise happened at (240 days) test age.

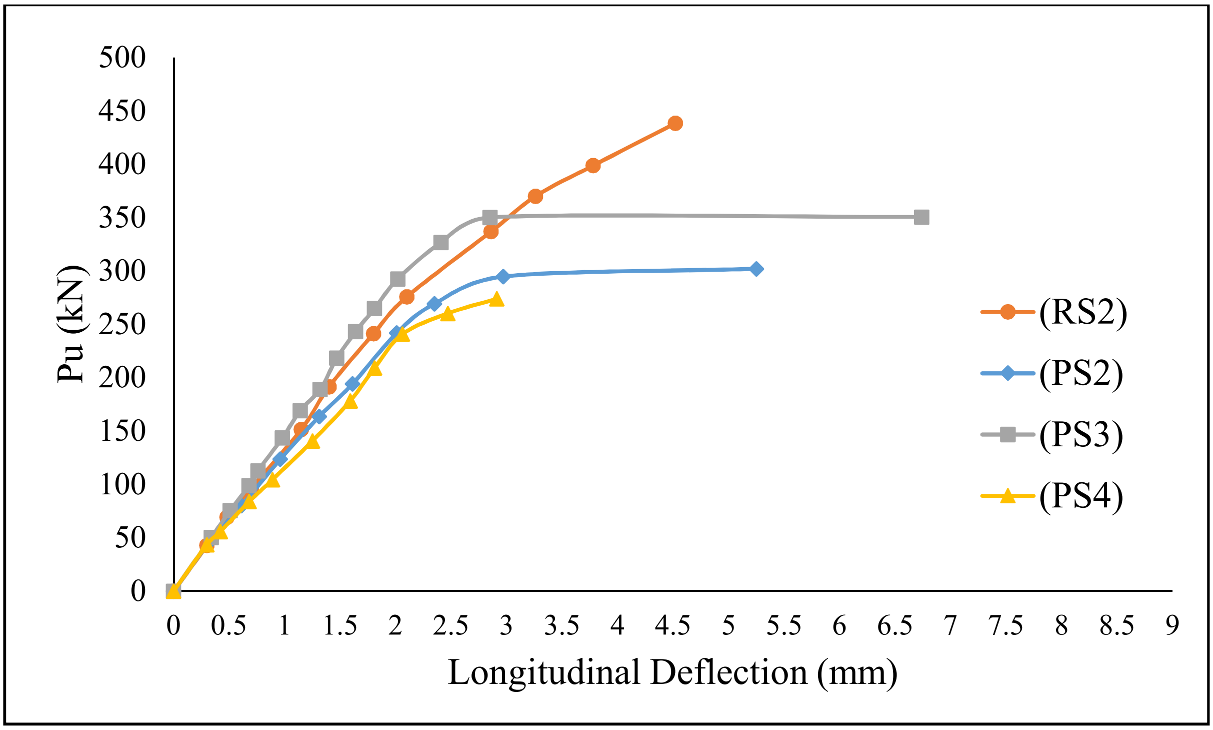

*Fig. (4-13): Load – Longitudinal Deflection Behavior of **Polymer** R.C. Columns Buried in the Sandy Soil*

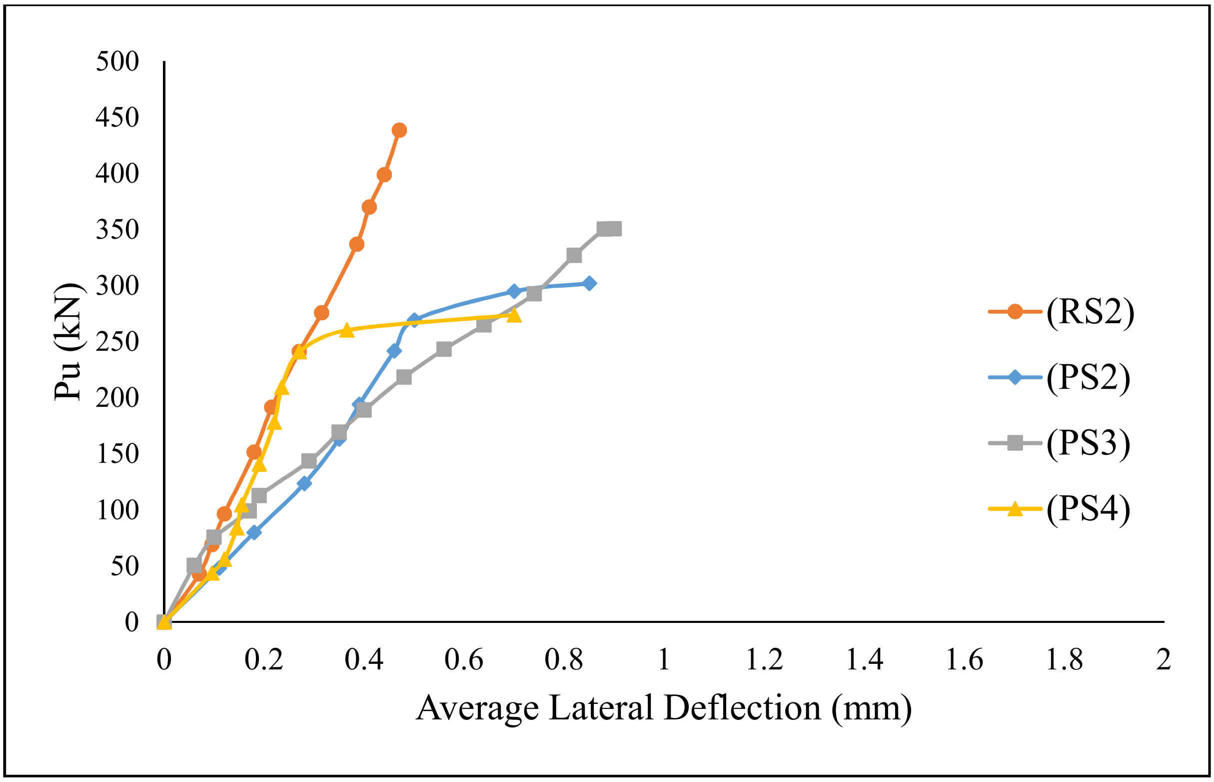

Fig. (4-14): Load – Lateral Deflection Behavior of ***Polymer*** *R.C. Columns Buried in the Sandy Soil*

4.6.3 High-Strength Reinforced Concrete Columns:

First cracks of the high-strength reinforced concrete columns group (Hs) were observed in top and bottom of these columns at the applied loads of (267.84, 302.4, 260.28 and 211.32) kN for the columns (RS3, HS2, HS3 and HS4), respectively. The small cracks developed in the tested columns are shown in *Plate (4-24)*. The size of these cracks increases with increasing applied load.

The group approached the ultimate loads at (785, 785.5, 637.92, and 752.3) kN for the columns (RS1, HS2, HS3, and HS4) respectively, *Plates (4-25) to (4-27)* show failure loads for the group (Hs).

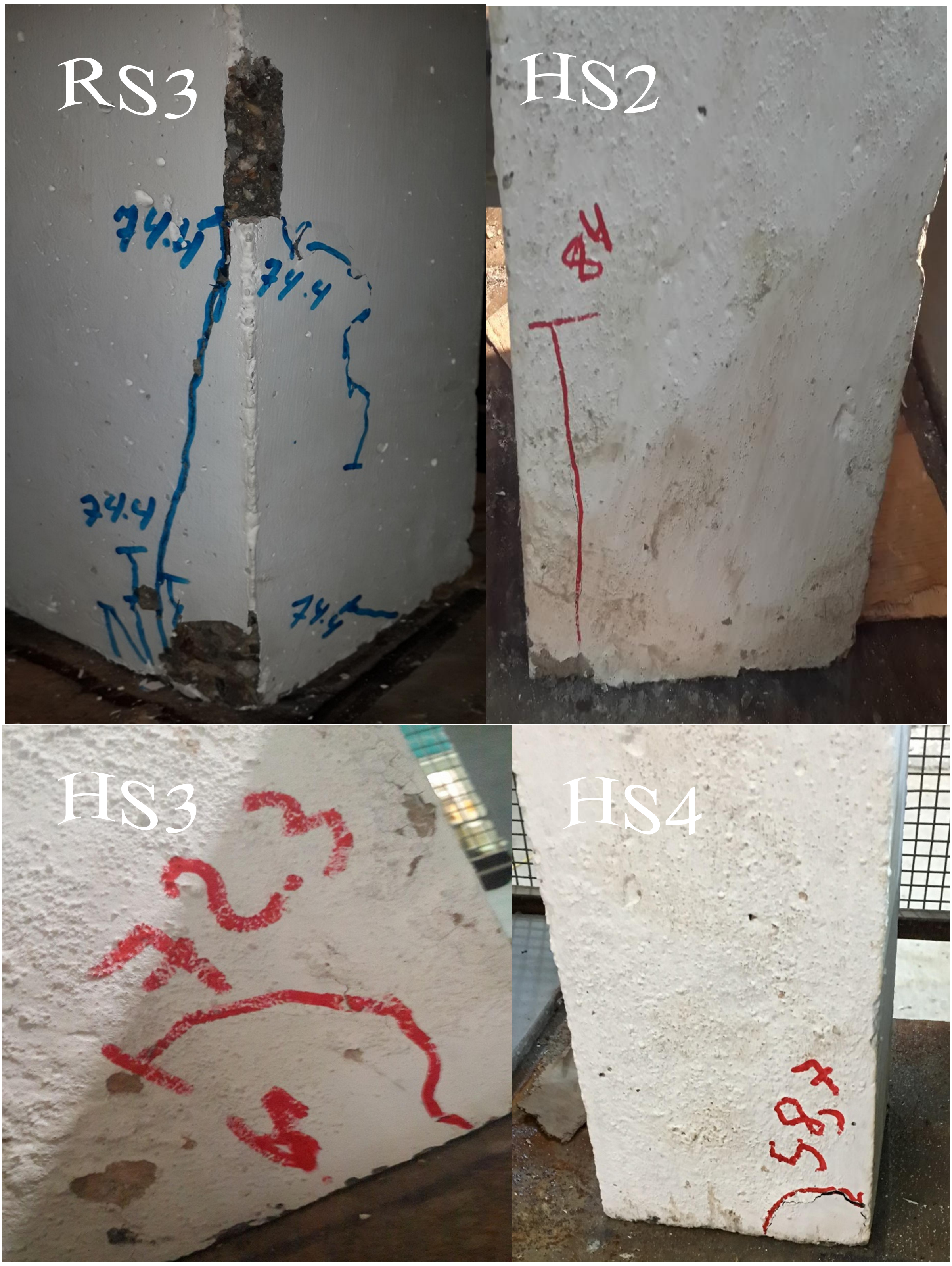

Plate (4-24): First cracks for group (Hs)

Plate (4-25): Failure Pattern for Column (HS2)

Plate (4-26): Failure Pattern for Column (HS3)

Plate (4-27): Failure Pattern for Column (HS4)

At developed age, it was found that the increase in the longitudinal deflection or still same due to the decrease in toughness and ductility of the columns. The failure in this group was almost sudden failure due to the high-strength of concrete mix and this reflected on the shape of load- deformation curves. In addition, the columns become less tough and ductile with time, these conclusions were covered by *Fig. (4-15)*.

As seen in the *Fig. (4-16)* the lateral deflection increases over time at the same load as example (600 kN), lead to increase the toughness and ductility of tested columns in transverse direction.

From *Table (4-2)*, it can be seen that the cracking load, and failure load of HS2, HS3 and HS4 to RS3 are (113, 97 and 78) %, and (100, 81 and 96) %, respectively.

It can be concluded from *Fig. (4-15)* and *Fig. (4-16)* that the best concrete mix tested is a high-strength concrete, whereas it was less effected when exposed to sulfate inside the sandy soil with time and this may be due to its efficiency and high-strength, which is reflected on the durability over time and slightly effected by harmful salts in the soil.

It was observed from the test results of high strenght columns buried in the sandy soil that the specimens were not effected at (60 days) age with a drop-in strength at (150 days) age. However, the strength returns to enhance at age of (240 days). This behavior is due to close of the specimen pores by fine particle of the sand which results in some healing in concrete matrix at this age.

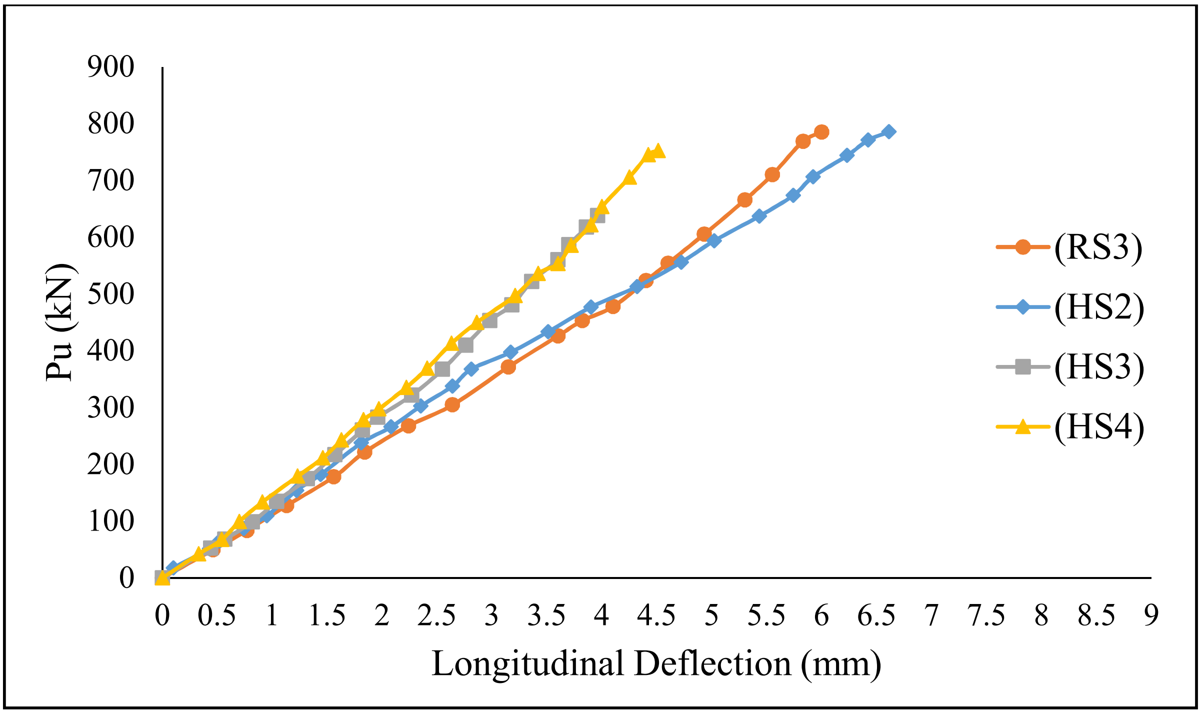

Fig. (4-15): Load – Longitudinal Deflection Behavior of ***High-Strength*** *R.C. Columns Buried in the Sandy soil*

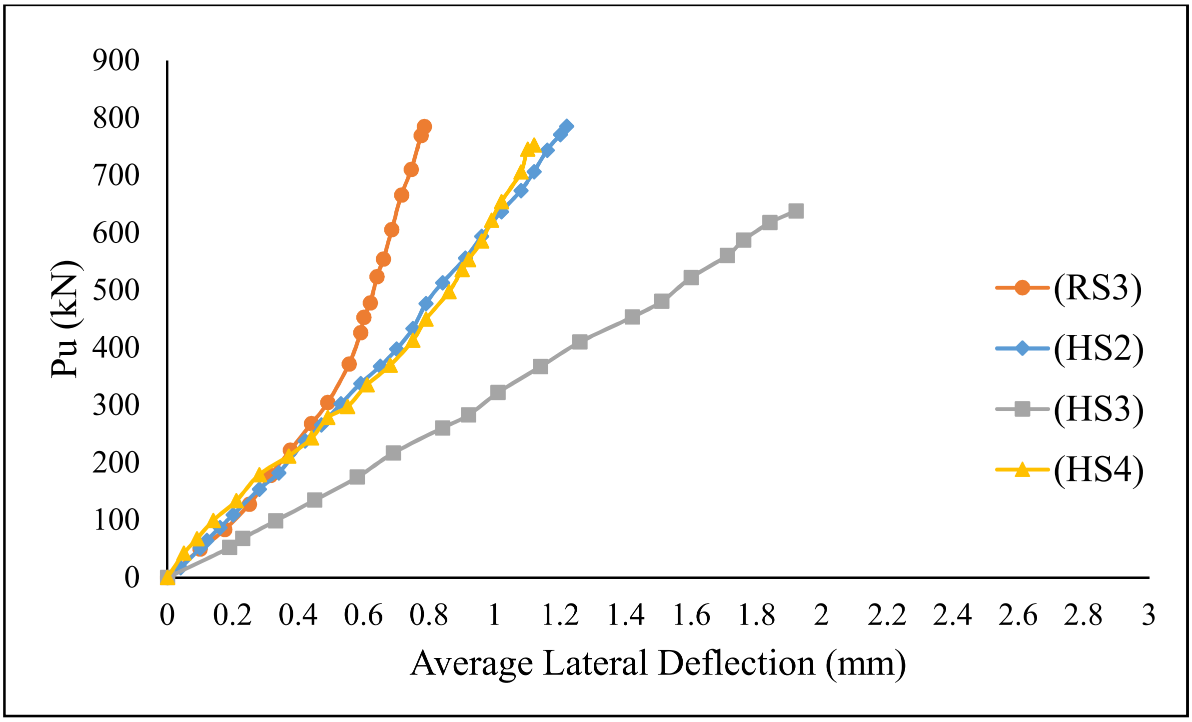

Fig. (4-16): Load – Lateral Deflection Behavior of ***High-Strength*** *R.C. Columns Buried in the Sandy Soil*

<u>4.7 Time Effect of Reinforced Concrete Columns Buried in Sandy Soil:</u>

Generally, reinforced concrete columns buried in the sandy soil were more effected to sulfate than reinforced concrete columns buried in the clayey soil specially polymer reinforced concrete columns, this may due to high concentration of sulfates and chlorides of the sandy soil.

At test age of (60 days), the highest decrease was recorded for normal and polymer reinforced concrete columns. The decrease was 11.27% and 31.12% for normal and polymer concrete columns, respectively compared with reference strength, while the high-strength columns still with the same strength without effected by aggressive solution on sandy soil.

As shown in *Fig. (4-17),* it was noticed a sudden failure in high-strength concrete column, while the failure was gradual in normal and polymer concrete columns. from the reuslts of load- deformation curves indicated that the high-strength mix was more ductile than the other mixes, while the polymeric mix was more brittle one. There is no penetration of sulfate inside columns for all columns at this test age.

At (150 days) the strength of normal and polymer mixes was enhanced, the decreasing was 20.03 % in polymer mix, while the increasing occurs in strength of normal mix was 6.98%, where the strength of high-strength mix decreased by 18.74 %. From load-deformation curves, *Fig. (4-18),* it was noticed that the failure is still sudden in high-strength column and gradual in normal and polymer columns but, with increasing in ductility of polymer columns. There was penetration for sulfate to the columns its values were (4, 6, and 1.5) cm in normal, polymer, and high-strength reinforced concrete columns respectively.

Finally, at (240 days) the increasing in strength of normal mix was 11.71%, and the decreasing in strength of high strength mix was 4.17% with respect to reference strength, while the strength of polymer mix decreased by 37.52% compared to the reference strength. As shown in *Fig. (4-19)* the failure was sudden in normal and high-strength columns and gradual in polymer columns with low ductility for polymer and normal columns. The penetration was (5 cm) in normal , (7 cm) in polymer, and (3 cm) in high-strength reinforced concrete columns.

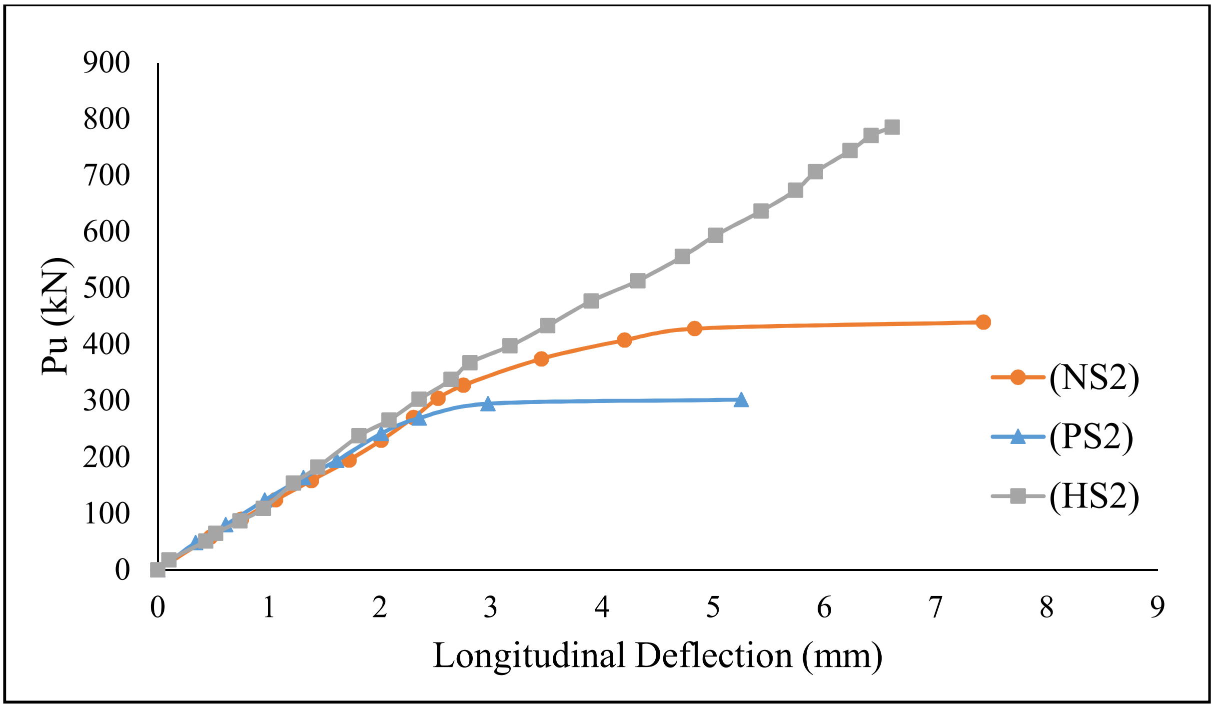

Fig. (4-17): Load – Longitudinal Deflection Behavior of ***Normal***, ***Polymer*** *and* ***High-Strength*** *R.C. Columns Buried in the Sandy Soil for* ***60 days***

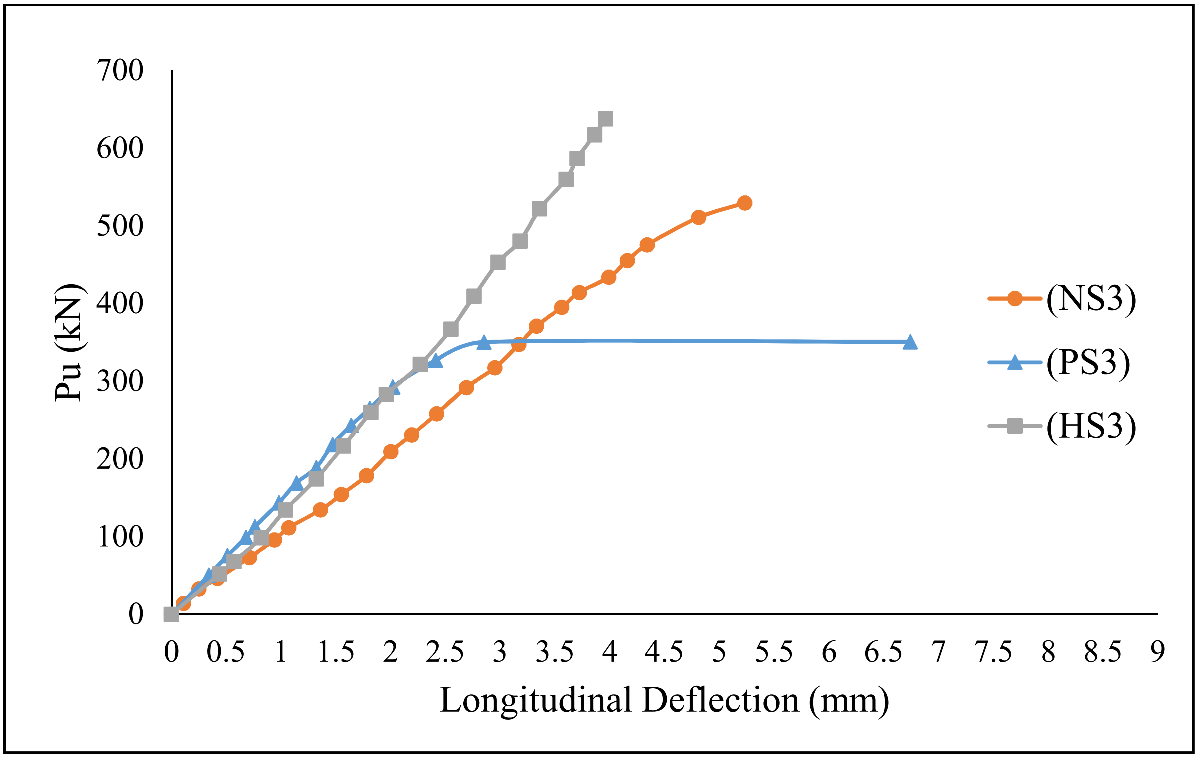

Fig. (4-18): Load – Longitudinal Deflection Behavior of ***Normal***, ***Polymer*** *and* ***High-Strength*** *R.C. Column Buried in the Sandy Soil for* ***150 days***

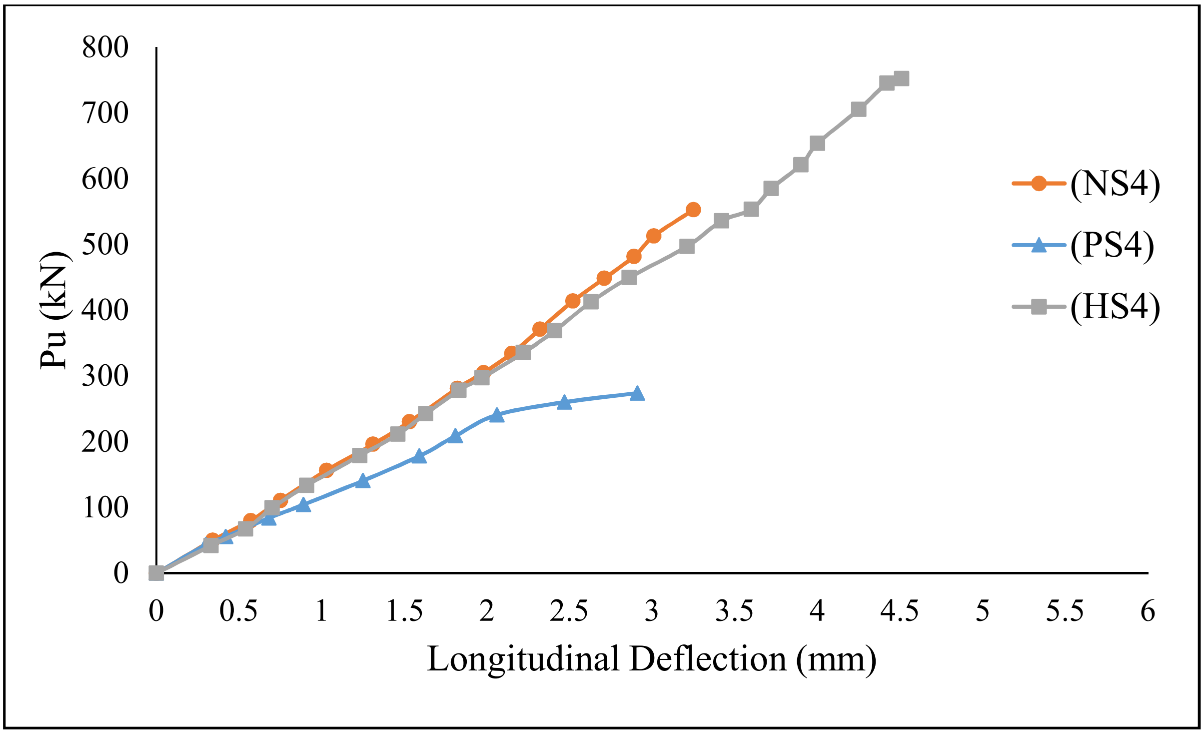

Fig. (4-19): Load – Longitudinal Deflection Behavior of ***Normal, Polymer*** *and* ***High-Strength*** *R.C. Columns Buried in Sandy Soil for* ***240 days***

4.8 Effect of Different Soil on Buried Reinforced Concrete Columns:

In general, the behavior of columns in the clayey soil did not differ significantly their behavior in the sandy soil, however the difference was in the extent to which compressive strength of columns was effected by the sulfate salts found in each soil.

4.8.1 Normal Reinforced Concrete Columns:

For the normal mix, the columns in the sandy soil were more ductile than the columns in the clayey soil, but the behavior of columns was relatively similar with a difference in the value of deformation and compressive strength recorded in each test, these shown in *Fig. (4-20) to (4-22)*.

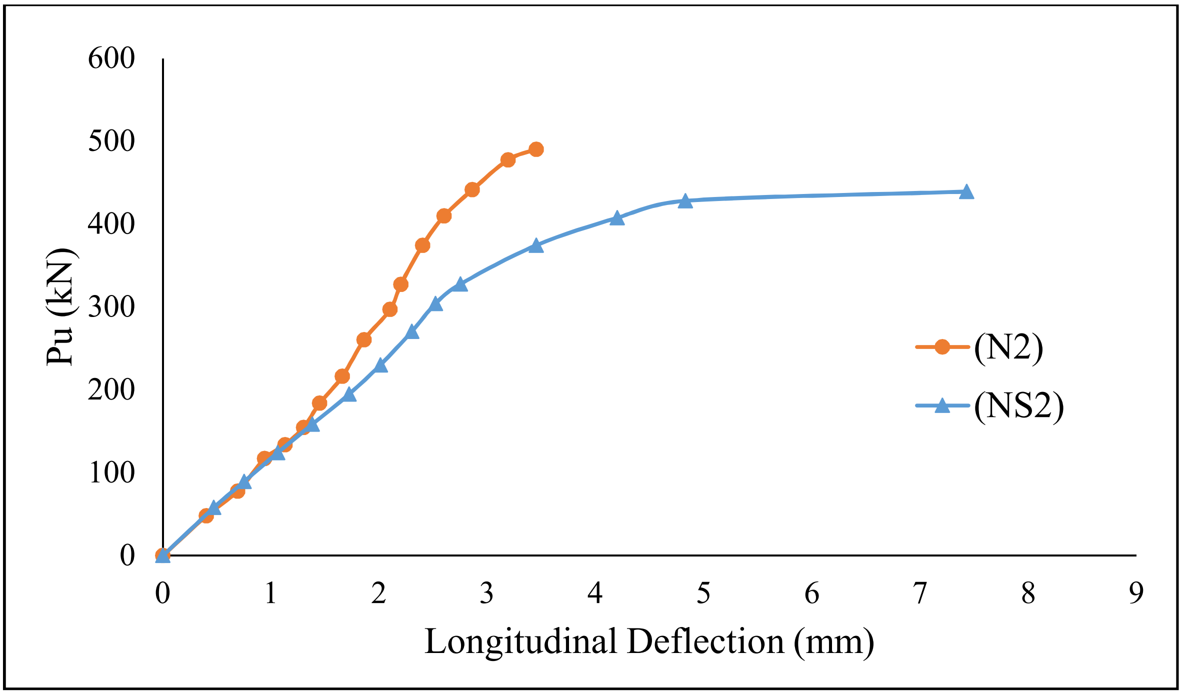

*Fig. (4-20): Load – Longitudinal Deflection Behavior of **Normal** R.C. Columns Buried in the Clayey and Sandy Soils for **60 days***

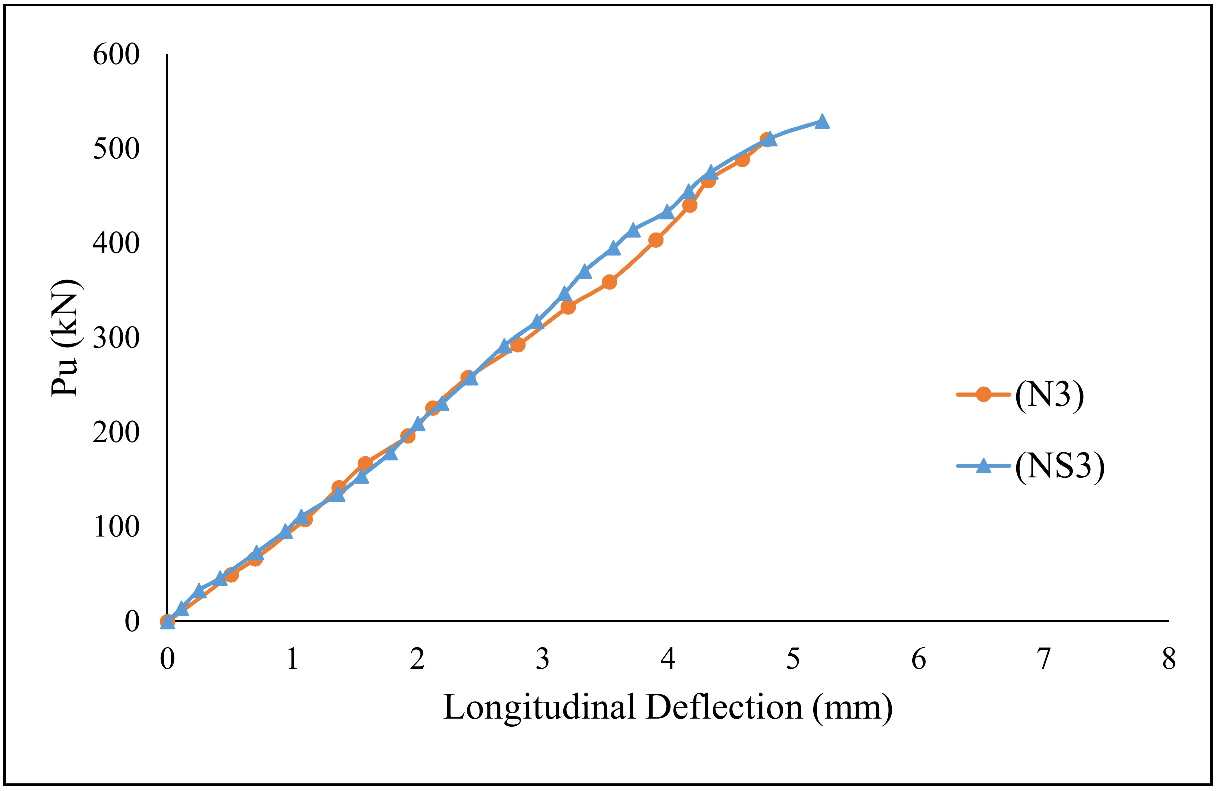

*Fig. (4-21): Load – Longitudinal Deflection Behavior of **Normal** R.C. Columns Buried in the Clayey and Sandy Soils for **150 days***

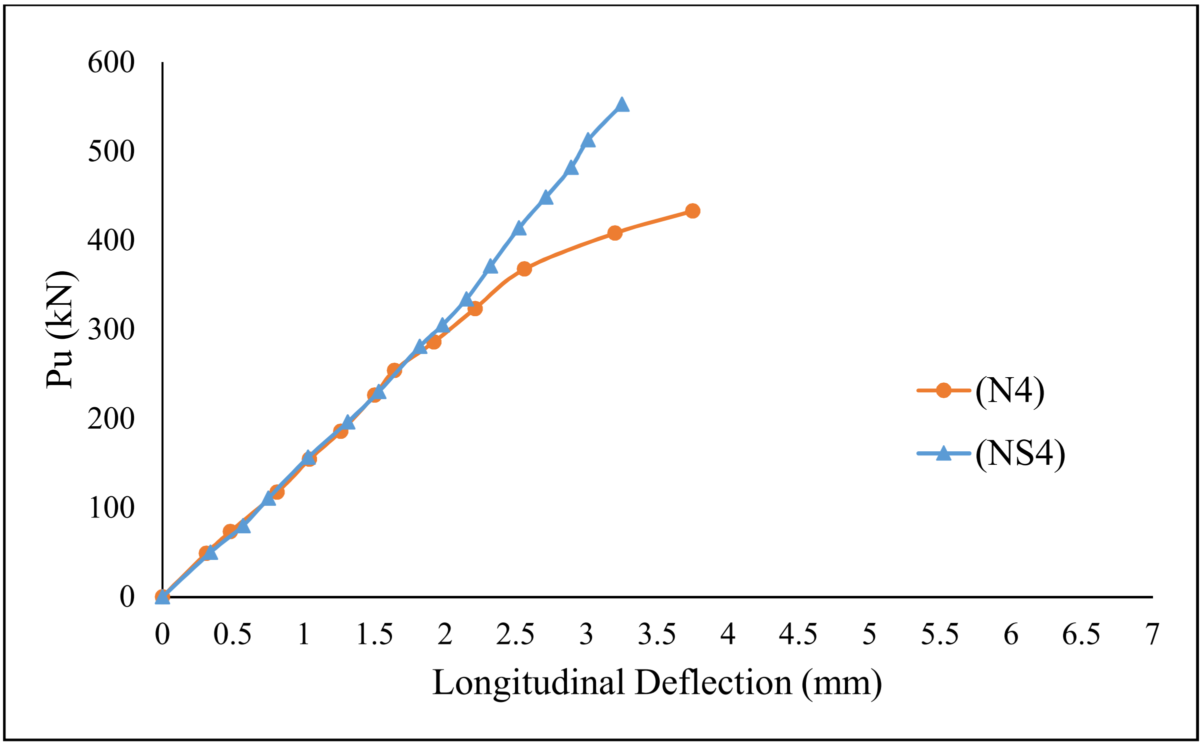

Fig. (4-22): Load – Longitudinal Deflection Behavior of ***Normal*** *R.C. Columns Buried in the Clayey and Sandy Soils for* ***240 days***

4.8.2 Polymer Reinforced Concrete Columns:

The high sulfate and chloride contents in the sandy soil are more affected and have a high impact on the columns specimens of polymer mix than at clayey soil. The factors effected were, the columns strength as well as the column ductility was less than the ductility of columns buried in the clayey soil. The columns in clayey soil had recorded high deformation with load increased, as shown in *Fig. (4-23) to (4-25).*

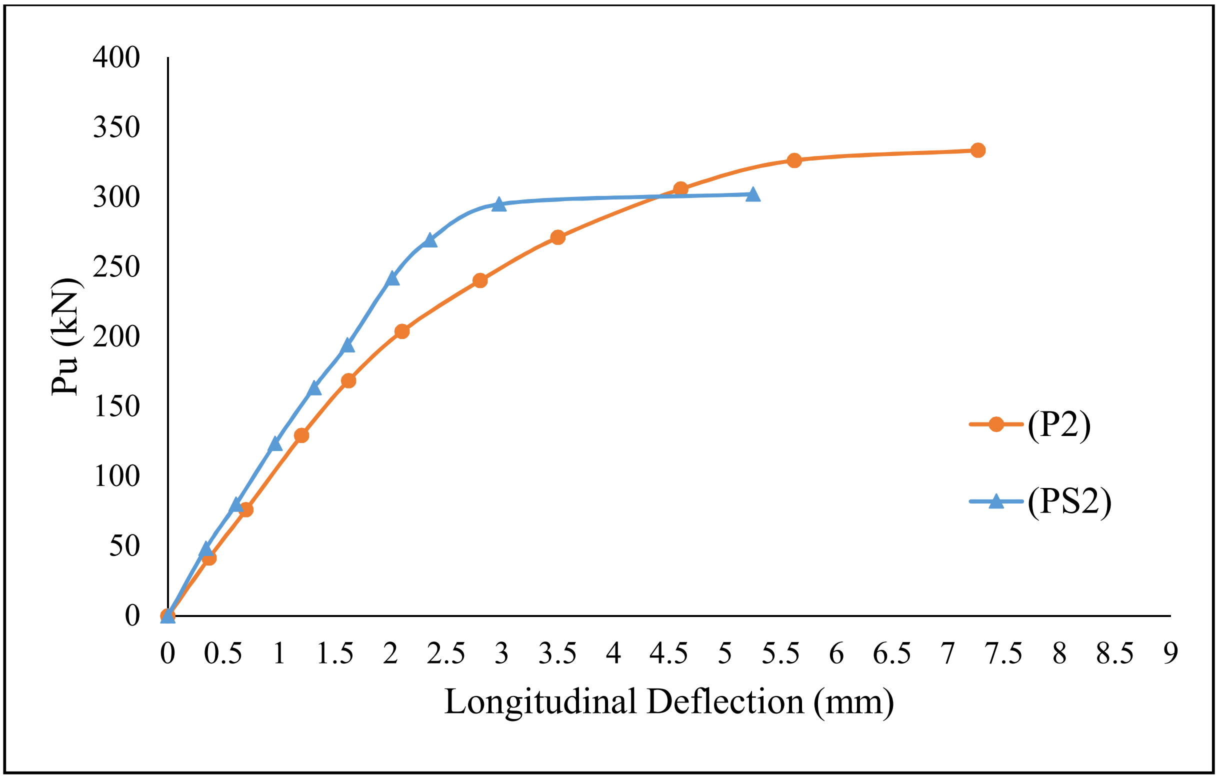

Fig. (4-23): Load – Longitudinal Deflection Behavior of ***Polymer*** *R.C. Columns Buried in the Clayey and Sandy Soils for* ***60 days***

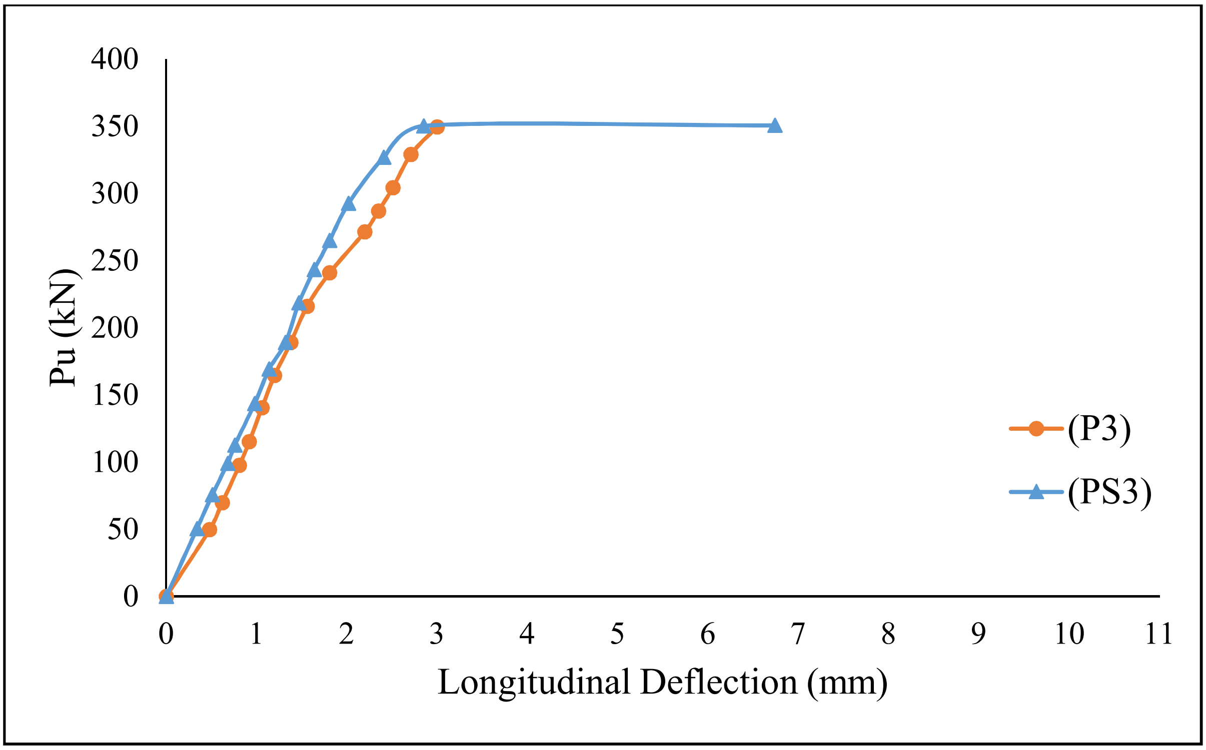

Fig. (4-24): Load – Longitudinal Deflection Behavior of Polymer R.C. Columns Buried in the Clayey and Sandy Soils for 150 days

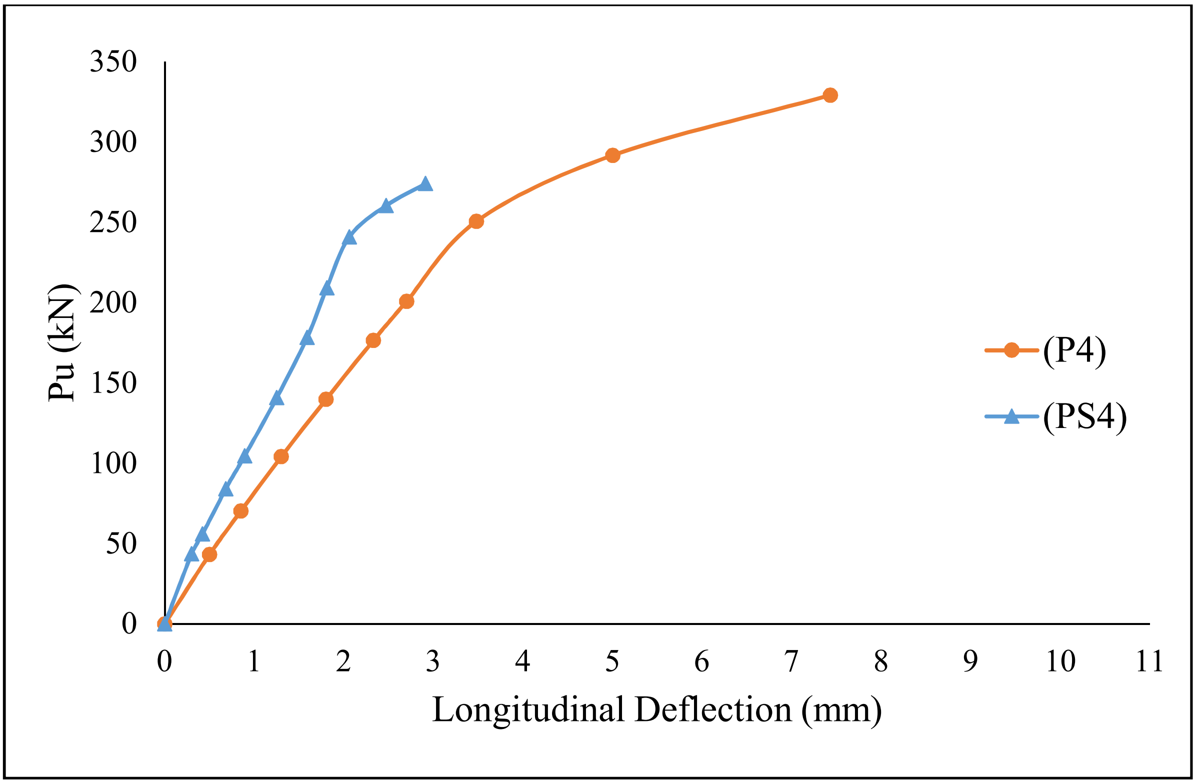

*Fig. (4-25): Load – Longitudinal Deflection Behavior of **Polymer** R.C. Columns Buried in Clayey and Sandy Soils for **240 days***

4.8.3 High-Strength Reinforced Concrete Columns:

The behavior of high-strength reinforced concrete columns was very similar in clayey and sandy soils with small difference in deformation values recorded at each load. The differences in compressive strength are illustrated in *Fig. (4-26) to (4-28).*

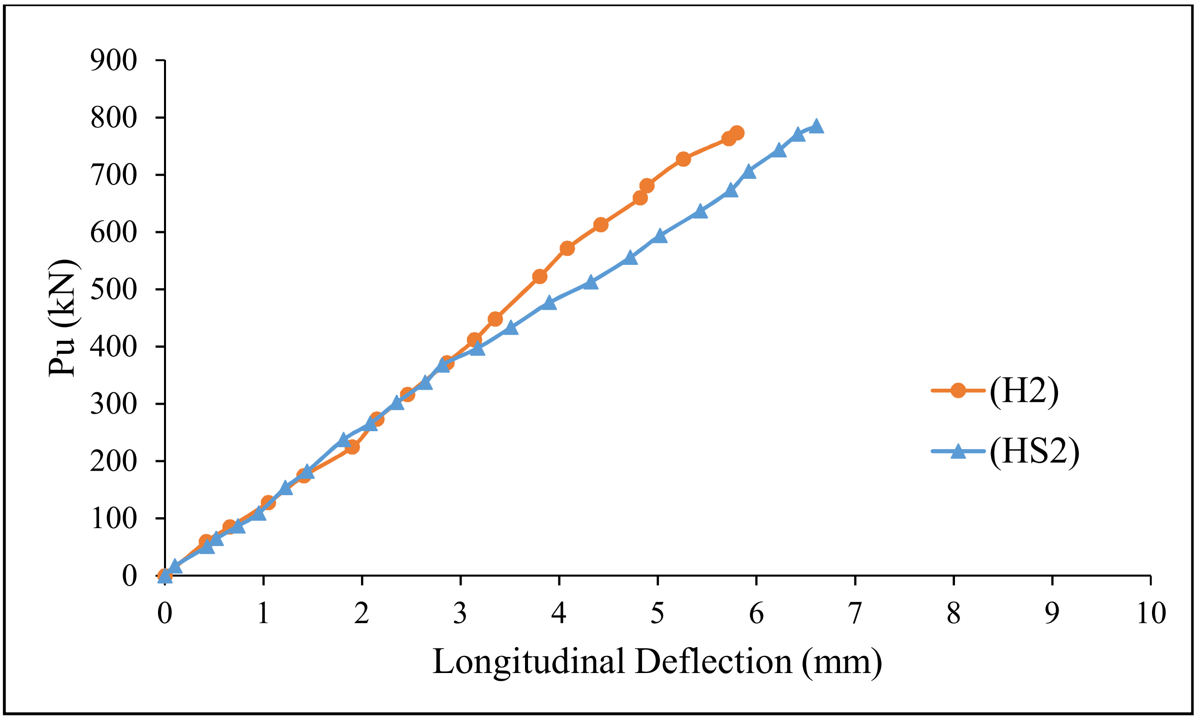

*Fig. (4-26): Load – Longitudinal Deflection Behavior of **High-Strength** R.C. Columns Buried in the Clayey and Sandy Soils for **60 days***

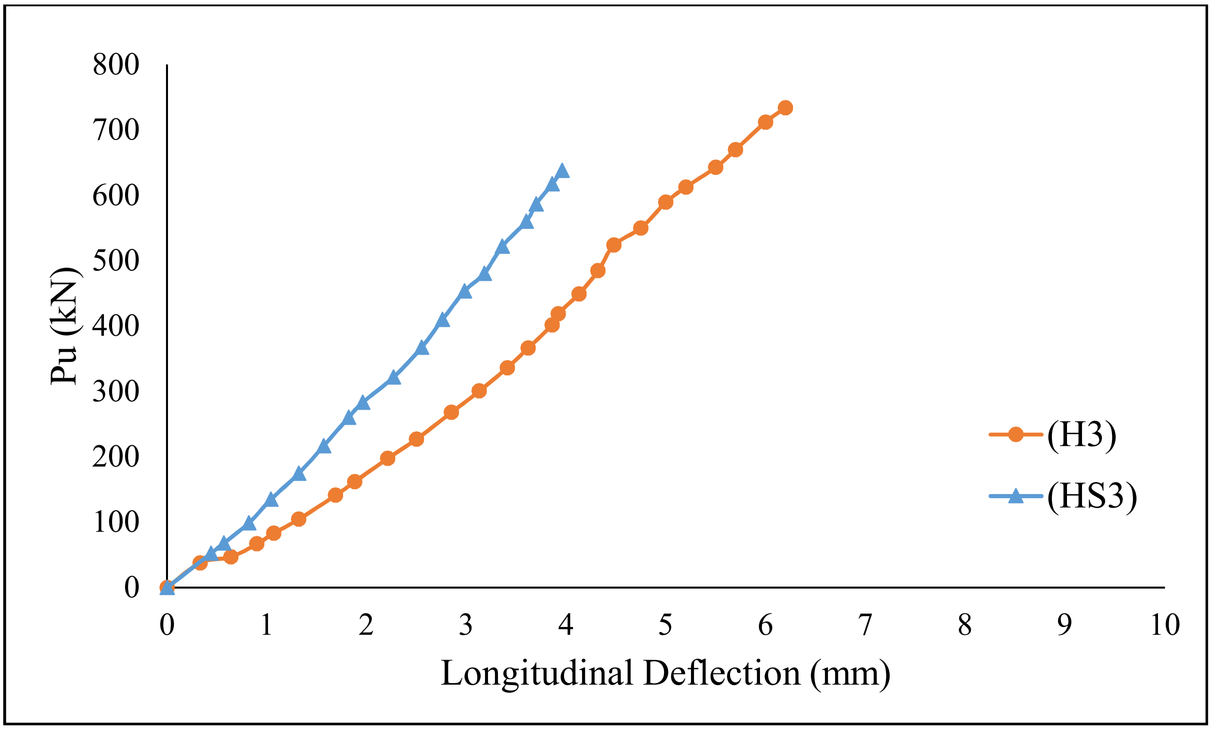

*Fig. (4-27): Load – Longitudinal Deflection Behavior of **High-Strength** R.C. Columns Buried in the Clayey and Sandy Soils for **150 days***

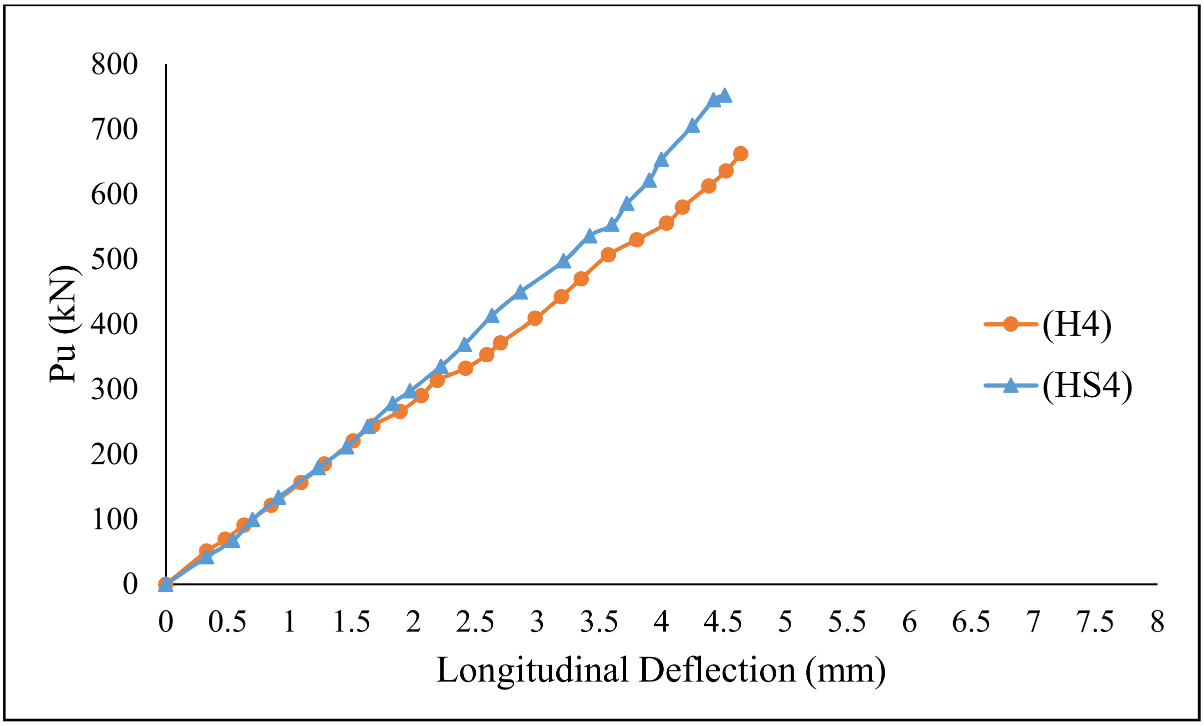

Fig. (4-28): Load – Longitudinal Deflection Behavior of ***High-Strength*** *R.C. Columns Buried in the Clayey and Sandy Soils for* ***240 days***

Chapter Five

Conclusions & Recommendations

CHAPTER FIVE

Conclusions and Recommendations

5.1 General:

In the previous chapters, an experimental program has been performed in order to study the behavior of R.C. columns buried in different types of soils.

In this chapter, conclusions obtained from the results and some recommendations for future studies are listed.

5.2 Conclusions:

On the basis of the observations made in the present work, the following conclusions were found:

1. All concrete mixes are affected through a bury in different soils, the degree of defect is depended on the mix design of the concrete matrix and on the concentration of sulfates found in that soils, as well the time of burying.
2. The best behavior under influence of harmful salts is recorded for high-strength mix, while the more affected mix by sulfates and chlorides is polymer mix showing high ductility.
3. Ductility increases with time in polymer concrete specimen buried in the clayey soil and it is decrease in specimen buried in sandy soil, while the ductility and toughness decrease in high-strength and normal columns buried in both the clayey and sandy soil.
4. The influence of exposure to contaminated soil becomes clear after (150 days) of exposure. The sandy soil has more effect than clayey soil on buried R.C columns. The degree of deterioration depends on salts concentration.

5. The higher decrease in strength capacity of normal R.C. columns is (12.5%) after exposure age of (240 days) for columns buried in the clayey soil, while the strength capacity of columns buried in the sandy soil is increased by (11.71 %) for exposure age (240) days, compared to the reference columns.
6. The higher decrease in strength capacity of tested columns for polymer concrete and high-strength concrete are (37.52 and 4.17) % respectively compared with reference columns after (240 days) buried in the sandy soil. While the strength capacity decrease for the same exposure period in clayey soil are (24.96 and 15.62) % for polymer concrete and high-strength concrete, respectively.
7. Failure of high-strength R.C columns is sudden and it is gradual failure in normal and polymer R.C columns.
8. The tensile strength of concrete cylinders increases with time of exposure up to (240 days) for all concrete mixes.
9. The absorption ratio decreases with time in normal concrete cubes, the ratio decreases at (240 days) age are (5.08 and 9.83) % for cubes buried in the sandy and clayey soils respectively compared with reference cubes.
10. The absorption ratio increases with time for polymer concrete cubes, the highest ratio of increase is recorded at (240 days) age (92.42 and 56.15) % for cubes buried in the sandy and clayey soils, respectively, compared with reference cubes. While in high-strength concrete cubes, the highest ratio of increase is recorded at (240 days) age (40.31 and 14.11) % for cubes buried in the sandy and clayey soils, respectively compared with reference cubes.
11. A decreasing in voids ratio with time in normal concrete cube is noticed the ratio recorded at (240 days) age are (4.57 and 7.79) % for cubes buried in the sandy and clayey soils respectively, compared with reference cubes.
12. A significant increase in voids ratio with time of exposure in polymer concrete cubes is noticed. For (240 days) exposure age the increase ratio is

(80.43 and 49.64) % for cubes buried in the sandy and clayey soils, respectively compared with reference cubes. While the voids ratio in high-strength concrete cubes is increased by (38.06 and 12.7) % for the same period of exposure for cubes buried in the sandy and clayey soils respectively, compared with reference cubes.

5.3 Recommendations for Further Studies:

There are several recommendations that can be considered for further experimental investigations regarding studying reinforced concrete columns buried in soils contained high concentrations of sulfate and chloride:

1. Investigating the resistance of other types of concrete mix to sulfate and chloride attacks.
2. Investigating the effect of other percentage of sulfates and chlorides salts on R.C. columns
3. Studying the effect of bury the R.C. columns in different soils for the time more than (240 days).
4. Research to Studying the effect of sulfates on the other hardened properties of R.C. columns such as impact strength, dynamic modulus of elasticity, microstructure of the damaged concrete by X-ray diffraction.
5. Studying columns subjected to uniaxial and biaxial bending.
6. Studying different types of structural members such as tie beams, spiral column.
7. Studying the behaviour of piles taking into account the soil simulation in the lab.

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الخلاصـــــــة

تعتبر مقـاومـة الخرســـــانـة لهجوم الكبريتـات واحدة من اهم الخواص للمحـافظـة على ديمومـة الخرسانة. أن الهدف الأساس من البحث هو تقييم أداء عدة أنواع من الاعمدة الخرسانية المسلحة المدفونة في حفرتين على عمق (3) أمتار بإحدى المناطق الزراعية في مدينة كربلاء المقدســـة، أحدهما تحتوي على تربة رملية بنســـبة املاح كبريتية (SO_3=10.609%) والأخرى تحتوي على تربة طينية بنســـبة املاح كبريتيـة (SO_3=2.61%). في هذا البحث تم انتـاج ثلاثـة أنواع من الخلطـات الخرســـــانيـة هي الخرســـانة الاعتيادية، الخرســـانة البوليميرية واخيراً خرســـانة عالية المقاومة. وقد تم عمل (21) عموداً خرسـانياً مسـلحاً و (126) مكعباً خرسـانياً و (63) أسـطوانة خرسـانية. وقد تم معالجة الاعمدة والنماذج الخرسـانية لمدة (28) يوماً بمياه صـالحة للشـرب ومن ثم دفنها في الترب ولمدة (60 , 150 , 240) يوم إضـــافة الى نماذج مرجعية غير مدفونة تم فحصـــها بعمر (28) يوماً. أجريت على النماذج مجموعة من الفحوصـات المختبرية وهي: (فحص مقاومة الانضـغاط للأعمدة الخرسـانية، فحص الانضـغاط للمكعبات الخرسـانية، فحص مقاومة الشـد للأسـطوانات الخرسـانية، وفحص الامتصـاص ونسـبة الفجوات والكثافة للمكعبـات الخرســـــانيـة). أظهرت النتـائج بـانـه تحت تـأثير الترب العدوانيـة (الحـاويـة على الكبريتـات والكلوريدات) يتأثر أداء الخرسـانة بجميع أنواعها الثلاثة المسـتعملة في هذا البحث تأثيراً سـلبياً مع زمن التعرض، وكان تدهور النماذج المدفونة في التربة الرملية اشـــد من النماذج المدفونة في التربة الطينية، كما ان مقاومة الخرسانة عالية المقاومة للترب العدائية كانت أفضل من أنواع الخرسانة الاخرى. حيث ان النسبة المئوية للنقصـان في مقاومة الانضـغاط للأعمدة الخرسـانية المعرضـة للمحاليل الملحية القاسية في التربة الطينية لكل من الخرســـانة الاعتيادية والبوليميرية وعالية المقاومة تراوحت بين (12.51-0.95) %، (24.96-20.28) % و (15.62-1.5) % على التوالي. وتراوحت النســـبة المئوية للنقصـــان في مقاومة الانضـــغاط للأعمدة الخرسـانية المعرضـــة للمحاليل الملحية القاســية في التربة الرملية لكل من الخرســـانة البوليميرية وعالية المقاومة بين (37.52-20.03) % و (18.74-0) % على التوالي، مقارنة مع الاعمدة الخرسـانية المرجعية غير المدفونة في الترب. اما الخرسـانة الاعتيادية فقد أظهرت زيادة في مقاومتها وصـــلت الى (11.71) % ولعمر فحص (240) يوم، مقارنة مع الاعمدة المرجعية كما وانه قد حدثت زيادة كبيرة في نســبة الامتصـــاص ونســبة الفجوات لكل من الخلطة البوليميرية والخلطة عالية المقاومة في حين انهما انخفضتا في الخلطة الاعتيادية.

جمهورية العــراق
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تصرف الأعمــــدة الخرســـــــــانية المســــلحة المغمورة في أنواع مختلفة من الترب العدوانية

رسالـــــة

مقدمة الى كلية الهندســة في جامعة كربلاء
وهي جزء من متطلبات نيل درجة الماجستيـــر
في علوم الهندسة المدنية / البنى التحتية

من قبـــــل
زهراء فاضل حنش
(بكالوريوس هندسة مدنية *2014*)

بأشراف

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تشرين الثاني *2017* م　　　　صفر *1439* هـ